A WiFi based Smart Wireless Sensor Network for an Agricultural Environment

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ABSTRACT

Environmental Monitoring Systems and Sensors systems have increased in importance over the years. However, increases in measurement points mean increases in installation and maintenance cost. Not to mention, the measurement points once they have been built and installed, can be tedious to relocate in the future. Therefore, the purpose of this Masters thesis is to present a project called "A Wi-Fi based Smart Wireless Sensor Network for an Agricultural Environment" which is capable of intelligently monitoring agricultural conditions in a pre-programmed manner. The proposed system consists of three stations: Sensor Node, Router, and Server. To allow for better monitoring of the climate condition in an agricultural environment such as field or greenhouse, the sensor station is equipped with several sensor elements such as Temperature, humidity, light, air pressure, soil moisture and water level. In addition investigation was performed in order to integrate a novel planar electromagnetic sensor for nitrate detection. The communication between the sensor node and the server is achieved via 802.11g wireless modules.

The overall system architecture shows advantages in cost, size, flexibility and power. It is believed that the outcomes of the project allow for opportunities to perform further research and development of a Wi-Fi based Wireless Sensor Network that is a portable and flexible type of sensing system for an Agricultural Environment.

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1) INTRODUCTION

1.1. AGRICULTURAL HISTORY

Agriculture has been around for thousands of years [1] allowing civilisations to expand by breaking away from nomadic lifestyles and building permanent settlements. It has an integral place in our current civilization and agricultural practices such as irrigation, fertilizers and use of greenhouses are wide spread. Agriculture is often characterized by enhanced productivity, and sometimes the reduction of human labour required.

Agricultural products are dependent upon environmental factors where plant growth and development are largely affected by the conditions experienced. Similarly diseases that occur due to environmental factors can cause plant growth to be significantly affected. To deal with environmental factors such as cold, wind and excessive sun new practices were implemented. For example, in the 13^{th} [2], 18^{th} and 19^{th} centuries [3] glasshouses, or greenhouses were developed; these allowed for the protection and cultivation of exotic plants imported to Europe that were acquired during travel expeditions.

Since the European colonisation of New Zealand, it has grown to become a largely agricultural dependent country, sometimes called "the world's biggest farm”. The environment in New Zealand allows for a wide variety of products. Kiwifruit, avocados, feijoas, peaches, plums, cherries, berries and more can be grown here.

1.2. INTRODUCTION TO PROJECT

Agricultural environments such as fields and greenhouses allow growers to produce plants with an emphasis on agricultural yield and productivity. In addition, it also provides the possibility to grow plants in environments previously not suited for the task. In particular, the use of greenhouses provides plants with protection from harsh weather conditions, diseases and a controlled environment.

An emphasis on agricultural yields however should be balanced with use of resources and sustainability [1][4]. This can only be done based on a deeper understanding and/or monitoring of the environmental systems. In particular the ongoing discussion will likely continue surrounding the potential for sustainable agriculture.

Agricultural environments are complex systems where significant changes in one environmental factor could have an adverse effect on another. Environmental factors can affect survival and growth, in particular with regards to germination, sprouting, flowering and fruit development. They can also indicate increased risk of disease and be used for prediction of upcoming changes in the environment. It is therefore of particular interest to monitor these environmental factors in particular for any control and management systems that might be implemented. Temperature, humidity, light, air pressure, soil moisture, water level are variables that are of interest to growers.

Manual collection of data for desired factors can be sporadic, not continuous, and produce variations from incorrect measurement taking. This can cause difficulty in controlling these important factors [5][6][7]. Sensor Networks have been deployed for a wide variety of applications [8] and awareness has increased with regards to implementing technology into an agricultural environment [5]. Sensor Networks are becoming the solution to many existing problems in industries with their ability to operate in a wide range of environments.

Sensor nodes can reduce the time and effort required to monitor an environment. This method reduces the risk of information being lost or misplaced. It would also allow placement in critical locations without the need to place personnel at risk. Monitoring systems can permit quicker response times to adverse factors and conditions, better quality control of the produce and lower labour cost. The utilization of technology would allow for remote measurement of factors such as temperature, humidity, atmospheric pressure, soil moisture, water level and light detection. Development is increasingly aimed towards wireless solutions as compared to wired-based systems [5][9][10]. One particular reason is that an agricultural monitoring system might require a large amount of wires and cables to distribute sensors. Sensor location can often require repositioning. Wireless nodes provide for flexibility of placement and additional sensors. A traditional wire layout would not provide this flexibility and could cost a substantial deal of time and energy in order to address such wiring problems [10][11].

The system aims to reduce the cost and effort of incorporating wiring and to enhance the flexibility and mobility of the selected sensing points while the wireless sensor network (WSN) looks at being a comparatively self-organizing system [11]. It allows sensor nodes to connect to the network and have their data logged to the allocated sensor server selected. The present work describes the development of a wireless system to monitor agricultural environments measure temperature, humidity, atmospheric pressure, soil moisture, water level and light. The wireless connection is implemented to acquire data from the various sensors, and to allow set up difficulty to be reduced.

It is important to see under what conditions agricultural products grow as compared to their optimum conditions, in order to try and put in place methods to maximize the growth potential of the product. The quality and productivity of crop plants is highly dependent on the management of resources and management of factors, which is dependent on the quality of the information gathered from the agricultural environment.

There has been rapid growth within the wireless communication industry. There are now many wireless technologies available on the market for both personal and industrial uses. Among these wireless technologies Wi-Fi is reported as one of the most exploited wireless technologies in use. Wi-Fi wireless technology is a widely used and often built in technology capable of using pre-existing hardware already available and serving other applications and hardware. The use of Internet Protocol (IP) is quite mature with readily available network management services making it a good choice for many environment monitoring systems.

Therefore, the objective of this project is to design and develop a Wi-Fi based Wireless Sensor Network for an agricultural environment capable of intelligently monitoring agricultural conditions in a pre-programmed manner that can be updated as required. The main advantages of the proposed design in comparison with previous works are:

- It has the ability to monitor agricultural climate parameters (temperature, relative humidity, light intensity, air pressure, soil moisture, water level).
- The system does not require cables to operate and has low power consumption.
- It comprises of wireless sensor nodes that can be used to collect environmental data.
- It allows communication between the server and sensor nodes that are located in different parts of an agricultural environment.
- Investigation into integrating Novel Planar Electromagnetic Sensor to sensor system for use in environment monitoring to detect nitrates and contamination in water sources.
- The system allows for battery operation, easy relocation once installed and maintenance that is relatively cheap and easy.

1.3. OUTLINE OF THE THESIS

The work done on the development of a Wi-Fi based Smart Wireless Sensor Network for an agricultural environment is described in the structure and arrangement of the report is as follows:

- Chapter 2 provides important background information on the agricultural climate factors and how they influence the development process of agricultural products. This section also briefly discusses some of the related existing work on agricultural monitoring systems.

- Chapter 3 is devoted to sensor technologies that were used for this particular research. This chapter also presents experimental results are also discussed in this chapter. It also describes investigation into integrating a novel planar sensor to the WSN802G module.
- Chapter 4 describes some of the existing wireless technologies. The feasibility of Wi-Fi is also explained in detail in this chapter.
- Chapter 5 explains and describes the hardware and software used for configuring the WSN802G Wi-Fi module. The chapter describes tests performed to investigate communication and achievable distance between WSN802G Wi-Fi module and Server using standard integrated antenna.
- Chapter 6 describes module integration and design specification. This chapter includes battery life reading and testing for energy consumption for the various transmissions. The chapter describes investigation into various battery types and energy harvesting systems. In addition it describes measurement of RF Signal Strength and the investigation into using RSSI for distance measurement.
- Chapter 7 describes the final design of sensor nodes its various parts and deployment. In addition it describes data logging for the WSN802G communications, the code used, files sizes, plotting, database information and experimental results.
- Chapter 8 describes the following conclusions that can be drawn from the Wi-Fi based agricultural sensor network project. It also contains recommendations for the further study and work to improve the system capability.

2) LITERATURE REVIEW

2.1. PLANT GROWTH BASED ON FACTORS IN AN AGRICULTURAL ENVIRONMENT

2.1.1. Introduction

During an agricultural product's development, it goes through various changes - these can include germination, sprouting, flowering and fruit development. As with many organisms it is affected by its environment in particular the availability of nutrients in the surroundings and the suitability of conditions. An agricultural environment can consist of a large number of factors including temperature, humidity, light, air pressure, soil moisture, water/nutrient/rainfall level. These factors can contribute or indicate how agricultural products develop either directly or indirectly, where poor environmental conditions can damage agricultural products, or increase the likelihood of diseases.

A deeper understanding of these environmental factors could allow growers greater awareness of potential issues that can have a negative effect on the development of agricultural products. It is of interest to monitor and possibly control these environmental factors in particular those that play an important role in agricultural products quality and productivity. Additionally appropriate action could be employed to prevent these conditions from occurring.

In the past there have been largely limited field tests with the deployment of a few relatively high cost sensors and sensing stations, thus limiting the coverage. The high cost of such systems usually made it difficult for interested parties to deploy a large number of sensing units. The hope was to have a sensor system able to measure a physical quantity and convert it into an electrical signal in order for it to be read and understood, be it by an observer or by an instrument.

Sensor technology has become commonplace in a wide variety of industry sectors, particularly where it is important to utilise information gained by monitoring and measuring the different sensors. Therefore there is some need to investigate the provision of reliable novel sensors that could be used in environmental monitoring systems and this should be carried out before interested parties such as environmental researchers contemplate taking on such systems.

2.1.2. Effects of Temperature

Temperature is a vital for agricultural environments. Agricultural produce is dependent on temperature as it will affect germination, sprouting, flowering and fruit development [12]. Additionally transpiration rates go up as the temperature goes up, especially during the growing season. Particular agricultural products have suitable temperature ranges which allow for growth and development. Temperatures below or above this range not only affect development and growth but can also stop processes essential for life such as the structure and functioning of enzymes[13]. Additionally temperature effects also include the possibility of ice formation or dehydration.

Temperature can cause changes indicative of possible changes occurring within other environmental factors such as relative humidity and soil moisture. Therefore monitoring the temperature is of particular interest.

2.1.3. Effects of Humidity

Humidity is of importance as when levels are too low or high, agricultural products can suffer. This is due to transpiration where the water is evaporating from the leaf surfaces

If humidity is below 50 percent for extended periods of time, growth can suffer as loss of water from leaves might be faster than replacement [12]. Due to this, plants growing in a dry environment can lose moisture overtime as it is easier for water to evaporate into dry rather than saturated air. Similarly if humidity is above 80 percent for extended periods risk and spread of disease can increase [12]. In such cases the agricultural product can be affected significantly - particularly the flowering and fruit development [5]. Different agricultural products have different transpiration rates.

2.1.4. Effects of Light

The presence of light and its duration is of significance as plants get energy from sun light [14]. Sunlight has an effect on photosynthesis and the pigment chlorophyll that gives plants their green colour [15]. It has an effect on growth processes of plants in agricultural environments, as strong sunlight causes greater transpiration where as plants grown in darkness are seen as weak plants lacking chlorophyll.

Hence, a balance between light and dark for plant growth allows for both better photosynthesis and transpiration. Monitoring light sources plays an important role in decision making associated with the flowering, blooming and ripening of produce [12][16].

2.1.5. Air Pressure as an Indicator

Air pressure measurement is a variable of interest, as it has relationship to other weather factors that might be used for prediction of upcoming changes in the environment. Low pressure is often associated with poor weather, with a rapid change in pressure occurring, meaning possible radical weather changes [16].

2.1.6. Effects of Soil Moisture and Water Availability

Agricultural produce, whether grown in soil or liquid nutrient, absorbs water through the root system and is lost through transpiration. "Leaf senescence" can be brought on by environmental stresses such as when soil moisture or water availability is lacking; it is an adaptive response to aid plant survival by reducing water loss from transpiration and redistributing nutrients [17]. The produce weight can be between 80 - 95 percent water where it can lose up to 98 percent of water intake via transpiration [15].

The reduction of available water results in roots failing to keep up with the rate of transpiration, therefore the plant responds with lower transpiration and photosynthesis through stomata response suffers.[18]. Where water is not limited, however, transpiration tends to increase and this has an effect on the amount of marketable product that can be obtained. Water is necessary for osmosis. [15]. The rate of water loss depends on the condition of soil, air flow, relative humidity and temperature of the environment.

Overly moist soil causes damage to the roots. A plant with damaged roots has problems extracting water and essential nutrients [15] and will eventually wilt and die over a period of time. Therefore, water is needed for agricultural products so that it has sufficient for the growth and life process but not so much that damage is done.

2.1.7. Effects of Nitrate

Nitrogen is one of the main elements that contribute to the growth of a plant [15] and is provided either via agricultural fertilizer and manure in soil based situations or liquid nutrient in a hydroponics situation. Investigation is planned for integrating the measurement of nitrates in water sources near agricultural environments [19]. A shortage of nitrogen can mean stunted growth and leaf yellowing. An excess of nitrates will affect the fruiting or seed development. This is also of interest due to the health concerns connected with nitrates for example Methemoglobinemia and its fatal consequence in infants caused by nitrate contamination [20].

Novel planar electromagnetic sensors have been fabricated and tested to allow for the detection of dangerous contamination in water sources such as nitrates. There is some desire to interface the novel planar electromagnetic sensor to detect water contamination via a WSN to allow for environmental monitoring.

2.1.8. Conclusions

The agricultural environment is the driving force behind the development of plants. The environment consists of many different factors that affect the developmental process of plants. Environmental factors are interrelated and cannot be considered singly due to their effect on the others, as well as on the plant. Some of these relationships are obscure; others are clear, but maybe easily overlooked. Therefore a good understanding of the effects of these climate factors and their relationships will allow for prevention and early detection of any potential problems.

2.2. EXISTING AGRICULTURAL MONITORING SYSTEMS

2.2.1. Introduction

There are several methods and systems available for monitoring agricultural environment. This section reviews a few existing monitoring systems that can be used to monitor an agricultural environment.

2.2.2. SAM System

The SAM system has the capability of monitoring up to four Hydra Probe II soil sensors. Each sensor station measures conductivity, salinity, temperature and measure flow of water and fertilizer from topsoil to sub-root zone [21]. It looks at the monitoring of remote crops with the hope of optimizing water and fertilization management. It allows for better resource usage and performs suitably in high-salinity soil. The Data collected by the SAM System in the field is transmitted to the user's base station PC.

The SAM System includes: [21]

- Four Hydra Probe II soil sensors
- A data logger for storing soil data
- A tipping bucket rain gauge for measuring precipitation and irrigation applications
- A radio telemetry system for transmitting the collected data to another location

Figure 1: SAM System [21]

2.2.3. DIAS Field Server

The DIAS Field Server monitors agricultural fields such as rice and maize. The platform contains an all-in-one PC set up [22][23]. The field server as a sensing network comprised of the devices, is designed and constructed in different shapes and functions based on the application purpose and deployed place. It contains a wireless transmitter distance that covers 100 m to 1000m around the field server. As a standard configuration it measures temperature, humidity, and light intensity and has a built-in web-camera. Additional options for the following sensors can be selected:

- Soil moisture
- Leaf surface condensation
- CO2 concentration
- UV （Ultraviolet radiation）
- Pest accounting

Figure 2: DIAS Field Server [23]

DIAS Field Server Can Contain: [23]

- Web Server
- Wi-Fi and/or Cellar-phone
- Cameras: 0.3-8M pixel
- Sensors: up to 24
- Ambient air temperature/humidity
- Solar radiation/UV

- CO_2 ,SO_2, NO_2, H_2S, CH_4
- Leaf surface condensation
- Soil moisture/temperature
- Water/Air pressure
- Insect, Rainfall gauge

2.2.4. Smart Farm System

The Smart Farm Field Monitor measures moisture level, temperature and data received from irrigation systems.[24] All Smart Farm System components transfer data through wireless to the hub. The data is transmitted to a computer, enabling you to view data and monitor farm variables. All data is saved in CSV files. Additionally the system can control irrigation systems and pond levels. It also allows for future enhancements to be made.

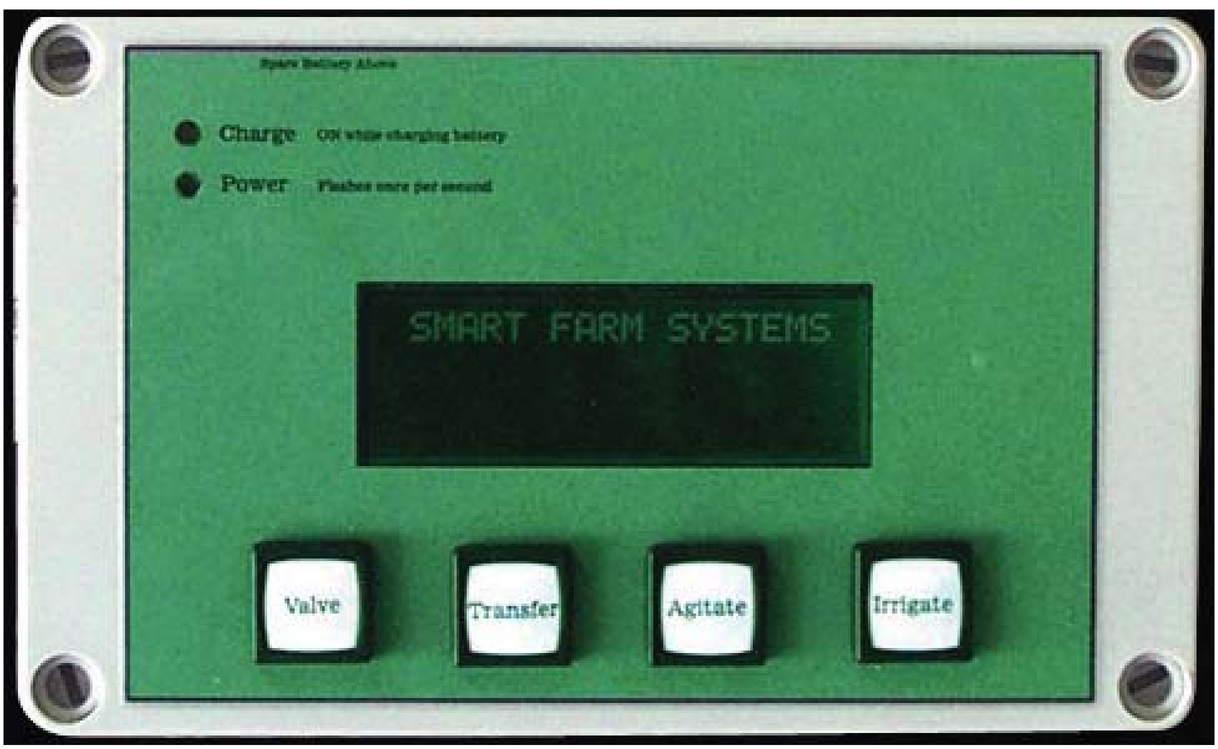


Figure 3: Smart Farm System Hub

2.2.5. Satellite Systems ERS / SAR

With regards to agricultural monitoring, there have been systems based on satellites such as ERS (European Remote Sensing Satellite) and Synthetic Aperture Radar (SAR) data [25]. The satellites are used to obtain information about soil properties and data can be collected and analysed in order to develop methods for improving agricultural statistics.

However, this requires additional information taken from conventional sources and employs remote-sensing. For example, the satellite measurements on ground monitoring for soil moisture, crop growth and production is usually done to support and confirm the remote sensing monitoring by ground data [26]. The Satellite system incorporates sophisticated interpretation techniques such as particular interactions between the radar beams and the crop in the presence of underlying water during the various stages of the growth cycle [25]. It also looks at agro-meteorological models

2.2.6. Conclusions

Looking at the issues and complexity of the existing systems we have designed and developed to monitor agricultural systems, it seems to overcome some of the weaknesses such as cost; power consumption; limited sensors implementation; feasibility of implementation; and cost of transmitting information. The developed system will be easy to use, reliable, portable, cost effective, scalable and monitor the agricultural environment in a pre-programmed manner.

3) SENSOR RESEARCH AND CONFIGURATION

3.1. INTRODUCTION

Sensor technology has become commonplace in a wide variety of industrial sectors in particular to utilise information gained by monitoring and measuring the different sensors. Therefore there is some need to investigate the sensor characteristics that could be used in agricultural environmental monitoring systems. This particular section of the thesis will be looking at some of the sensor technologies that are used in this particular research.

The commercially available sensors investigated for this project are: D600 temperature sensor, HIH-4010 Humidity sensor, APDS-9002 Miniature Surface-Mount Light Photo Sensor, NPP-301 Series NovaSensor Surface Mount Pressure Sensor and VG400 soil moisture sensor. Integration of Novel Planar Electromagnetic Sensors for Detection of Nitrates [2] was also investigated. This section gives some insights on the construction of each sensor and their key features. Experimental results are also discussed in this section.

3.2. DS600'S CHARACTERISTICS AND CONSTRUCTION

The DS600 [27] Temperature Sensor is a part of the Maxim Integrated Product line. The DS600 is an accurate analogue-output temperature sensor. Thermometer Error ±0.5°C Accuracy for -20°C to +100°C and ±0.75°C Accuracy and it has a Temperature Range of -40°C to +125°C. This accuracy is valid over its entire operating voltage range of 2.7V to 5.5V. Aside from the inbuilt sensing technologies, the DS600 also contains some control logic, a level-shift buffer and thermostat comparator. As such the D600 has a shutdown function that can put the device into a low-power standby mode and a user-programmable thermostat function. The DS600 analogue temperature sensor measures it own temperature. These measurements are provided in the form of an output voltage, V_{OUT} that is linearly proportional to degrees centigrade. The output voltage characteristic is factory-calibrated for a typical output gain and a DC offset.

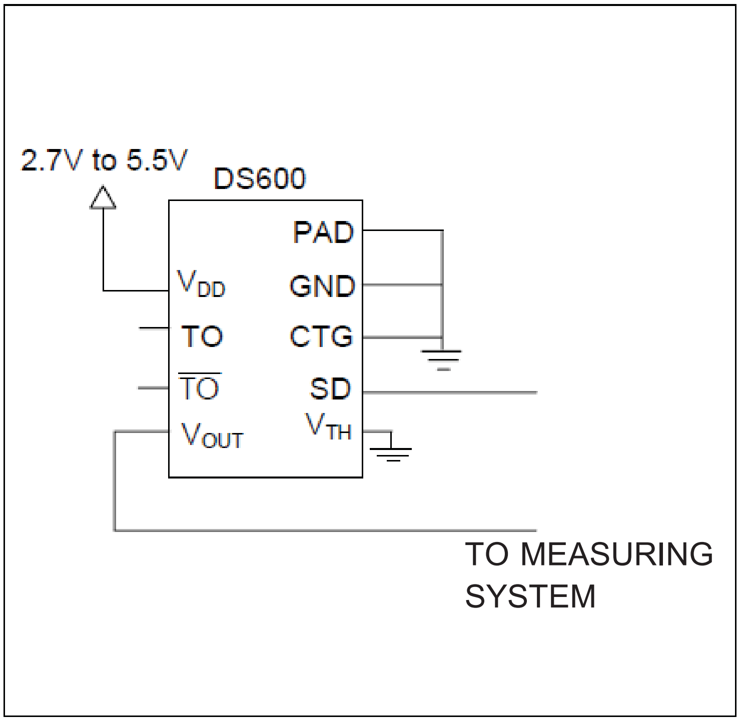


Figure 4: A Typical DS600 Connection Layout [27]

A typical application circuit is shown on (Figure 4). The sensor comes in a 8-pin µSOP package: V_{DD}, TO, !TO, V_{OUT}, V_{TH}, SD, CTG, and GND pin, where TO and !TO are thermostat output and could be used for the thermostat trip-point. V_{OUT} is the temperature output, where the voltage output is proportional to the temperature in degrees centigrade. V_{TH} is the user-selectable voltage that sets the thermostat trip-point temperature where TO and !TO output transitions are triggered when V_{OUT} crosses this voltage. The SD in allows for shutdown where power consumption and thermal sensor function can be controlled and functions as an active-high input pin. Driving this pin high puts the device in a low-power state and discontinues thermal sensing. A voltage source (V_{DD}) between 2.7V to 5.5V is required to power the sensor.

The voltage output (V_{OUT}) is connected to the ADC pin on the measuring system. This can either be done directly or through various buffers, signal gating and voltage protection systems. The temperature output voltage characteristic can be seen (Figure 5).

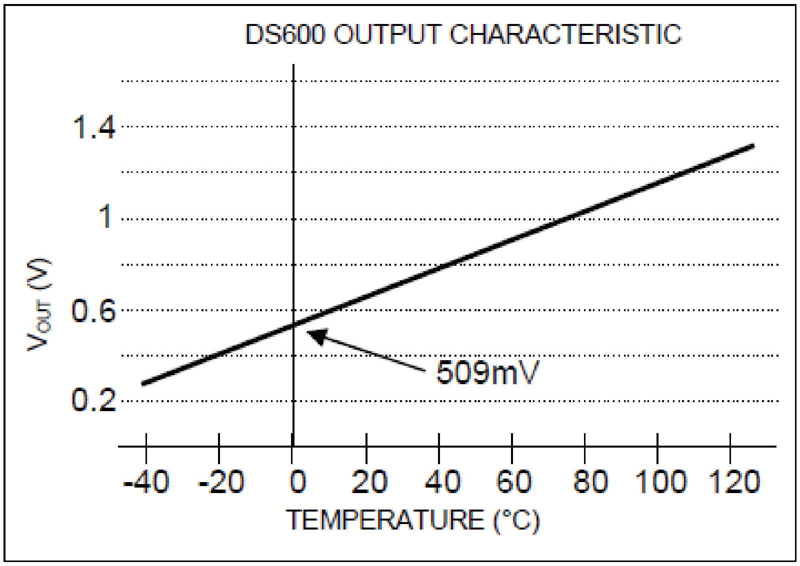


Figure 5: Temperature Output Voltage Characteristic [27]

The DS600 analogue temperature sensor measures temperature and provides these measurements as a voltage output (V_{OUT}). V_{OUT} value can then be used to calculate the value of temperature (T). This is based upon the DS600 electrical characteristics for offset (V_{OS}) at 0°C and output gain (ΔV/ΔT). The temperature can be expressed using equation (3.2.2):

$$V_{OUT} = (\Delta V / \Delta T) \times T + V_{OS} \qquad \textbf{(3.2.1)}$$

$$T = \frac{(V_{OUT} - V_{OS})}{\Delta V / \Delta T} \qquad \textbf{(3.2.2)}$$

Where:

- V_{OS} is equal to 509mV
- ΔV/ΔT is equal to 6.45mV/°C
- V_{OUT} is the Voltage Temperature Output from Sensor
- T is Temperature in Degrees Celsius

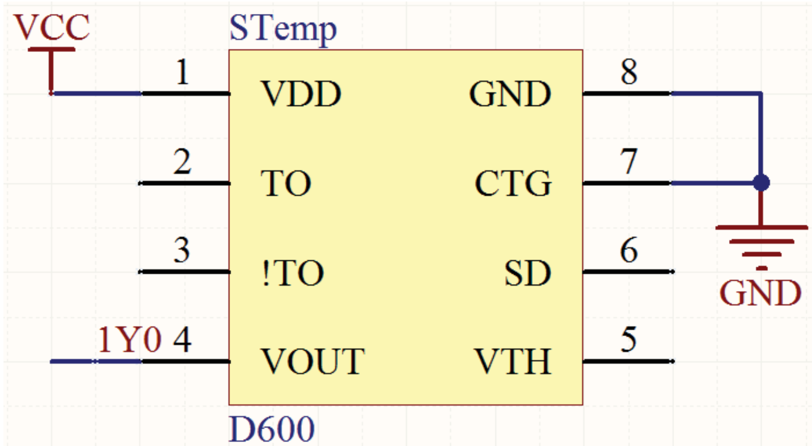


Figure 6: Configuration of DS600 Temperature Sensor

Measurements logged for temperature taken within an enclosed hydroponic greenhouse area can be seen over a 24 hour period (Figure 7).

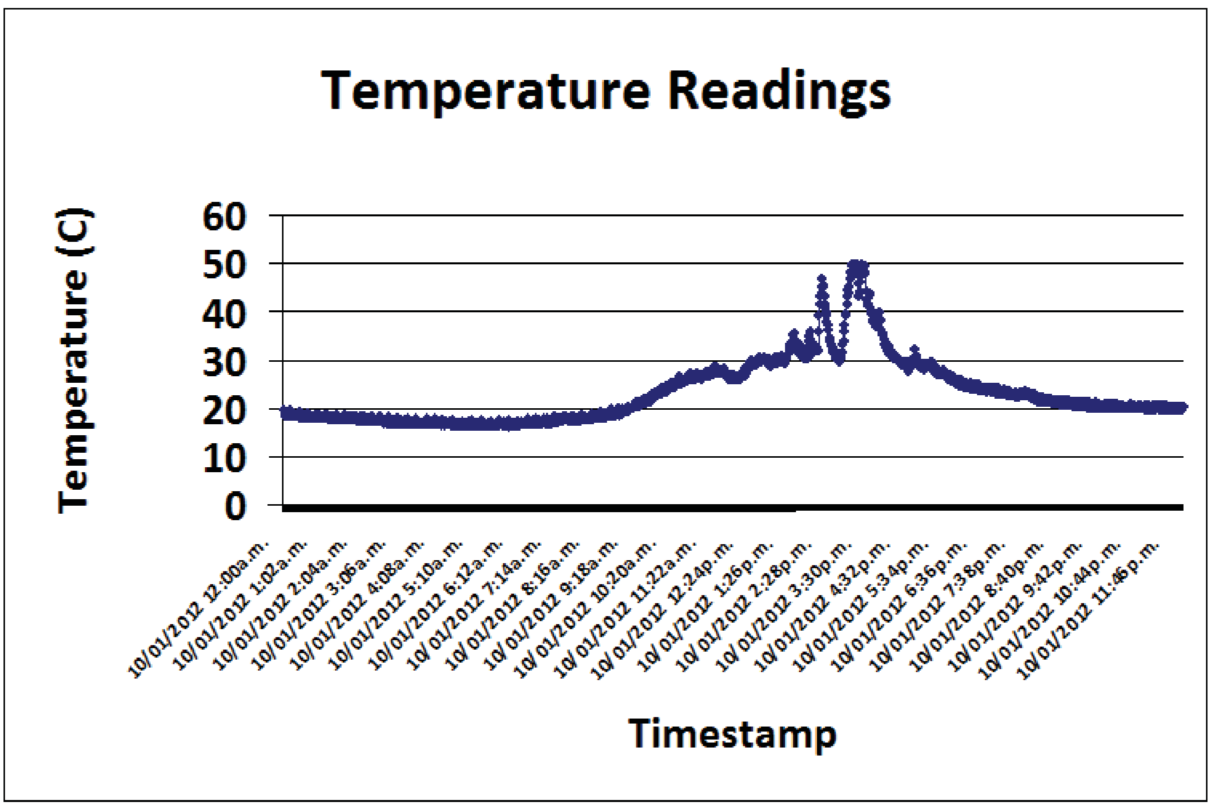


Figure 7: Logged Data for DS600 Temperature Sensor Output

3.3. HIH-4010 'S CHARACTERISTICS AND CONSTRUCTION

The HIH-4010 series humidity sensor produced by Honeywell [28] is designed specifically to direct input to a controller or other device. HIH-4010 has a near linear voltage output. The HIH-4010 series uncovered integrated humidity sensor delivers instrumentation quality RH (Relative Humidity). The RH sensor is a laser trimmed, thermoset polymer capacitive sensing element with on-chip integrated signal conditioning.[28]. The sensors construction provides excellent resistance to most application hazards such as dust, dirt, oils and common environmental chemicals.

Various calculations are needed in order to get the humidity value from the analogue output [28]. There is a need to calculate the sensor's relative humidity (RH) value dependent upon voltage supply (VSUPPLY) (3.3.1). It is important to know voltage supply over different periods for a system that would run off battery power. As both the humidity sensor and WSN802G module run on the same power supply, the regular voltage readings by the WSN802G can be used for calculation. Some compensation for temperature (T) (3.3.2) which will be acquired from the DS600 temperature sensor [16] is also required. The voltage divider configuration implemented also needs to be considered when performing the calculation of the result (3.3.3).

$$V_{SensorOut} = V_{Supply}\left[0.0062\left(SensorRH\right) + 0.16\right] \quad \textbf{(3.3.1)}$$

$$RH_{TempCom} = \frac{SensorRH}{1.0546 - 0.00216T} \quad \textbf{(3.3.2)}$$

$$V_{OutDiv} = \frac{HR2}{HR1 + HR2} V_{SENSOROUT} \quad \textbf{(3.3.3)}$$

The system uses the HIH-4010 humidity sensor produced by Honeywell. The HIH-4010 provides an analogue output [28] that is connected to a voltage buffer followed by a voltage divider configuration (Figure 8). This is for the voltage value to be within the WSN802G ADC's voltage range. The voltage output is then connected to one of the multiplexer channels allowing for selection to one of the WSN802G ADCs.

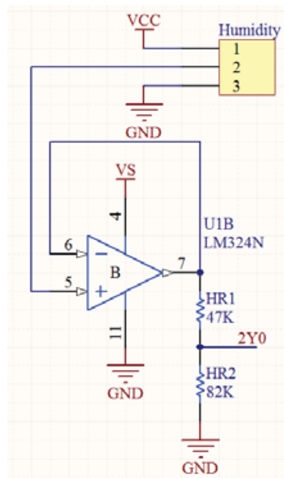


Figure 8: Configuration of HIH-4010 Humidity Sensor

Logged measurements for humidity within an enclosed hydroponic area can be seen over a 24 hour period (Figure 9).

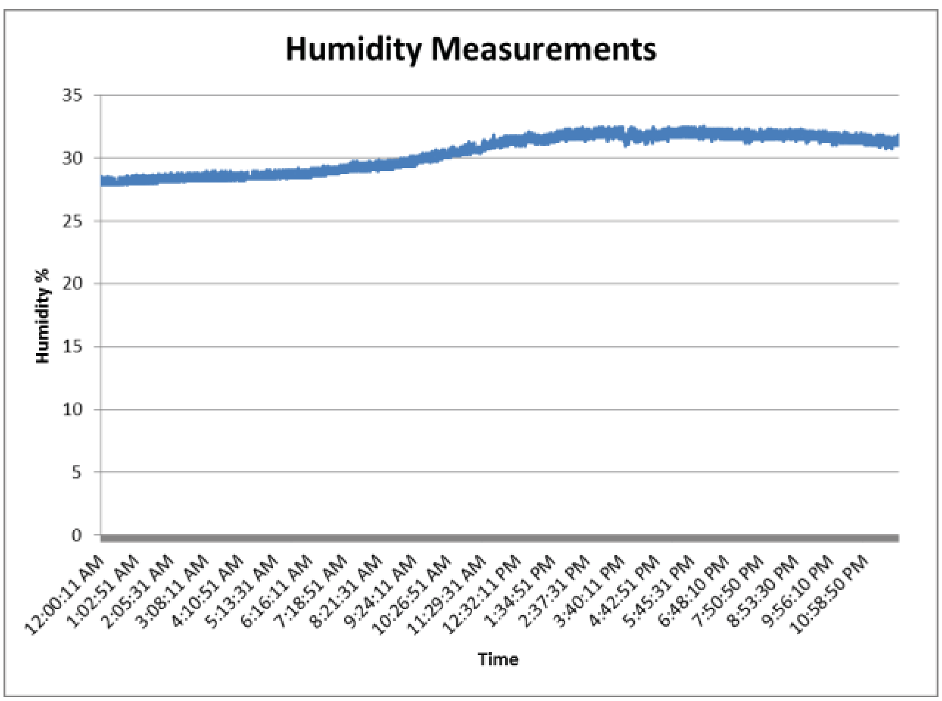


Figure 9: Logged Data for HIH-4010 Humidity Sensor

3.4. APDS-9002 AMBIENT LIGHT PHOTO SENSOR CHARACTERISTICS

The system investigates the use of an APDS-9002 ambient light photo sensor. The analogue output of the sensor connects to a load resistor and filtering capacitor (Figure 10). There after it is connected to a voltage buffer followed by a voltage divider, then connected to a multiplexer channel allowing for selection to one of the WSN802G ADCs.

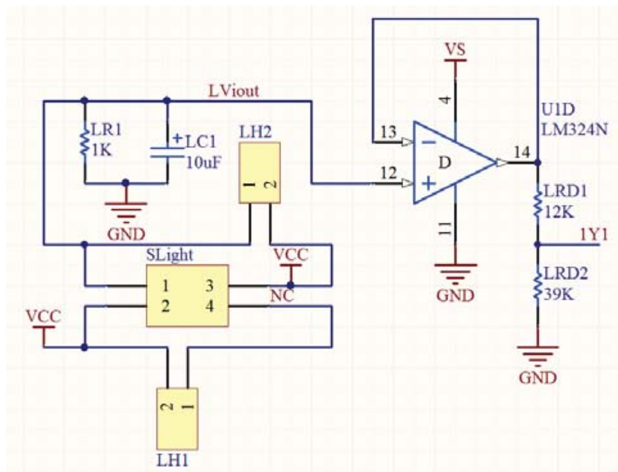


Figure 10: Configuration of ADPS-9002 Light Sensor

The relationship between the change in sensor output and light intensity (Lux) can be calculated using the following equation (3.4.1) where the voltage divider configuration implemented also needs to be considered when performing the calculation of the result (3.4.2).

$$Lux = V_{SENSOROUT} \frac{1000}{2.4} \quad \textbf{(3.4.1)}$$

$$V_{OutDiv} = \frac{LRD2}{LRD1 + LRD2} V_{SENSOROUT} \quad \textbf{(3.4.2)}$$

The ADPS-9002 produces a current output that can be converted to a voltage using an external resistor LR1 [29]. The value of the resistor determines the current-to-voltage conversion (Figure 11) [29]. The capacitor in parallel with the resistor acts as a low pass filter to deal with certain noise present.

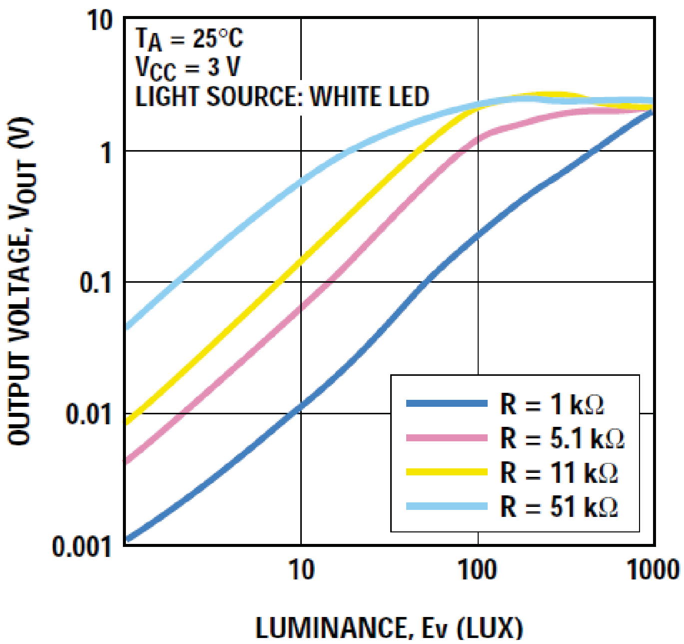


Figure 11: ADPS-9002 Specification for Output Voltage vs. Illuminance at Different Load Resistor

Measurements logged for light within an enclosed hydroponic area can be seen over approximately a 24 hour period (Figure 12).

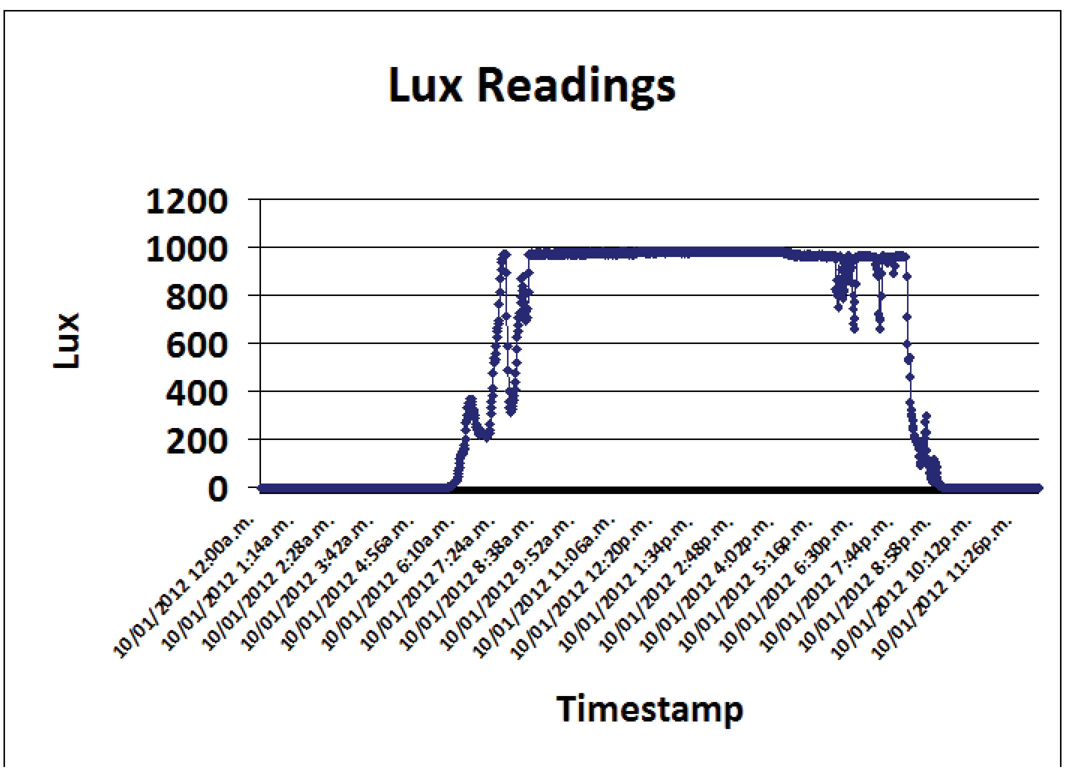


Figure 12: Logged Data for ADPS-9002 Light Sensor

3.5. NPP-301 PRESSURE SENSOR CHARACTERISTICS

The system investigates using a NPP-301 Nova Sensor Pressure Sensor (Figure 13) produced by GE Industrial sensing which has the voltage output linearly proportional to input pressure [30].

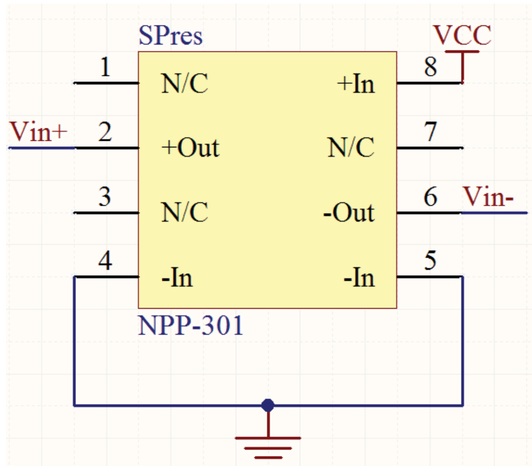


Figure 13: Configuration of NPP-301 Pressure Sensor

The system implements an instrumentation amplifier in order to amplify the differential signals from the NPP-301 bridge sensor (Figure 14). The NPP-301 parameters have a full scale output of 60mV, linearity of ±0.20%FSO and offset of ±10mV/V.

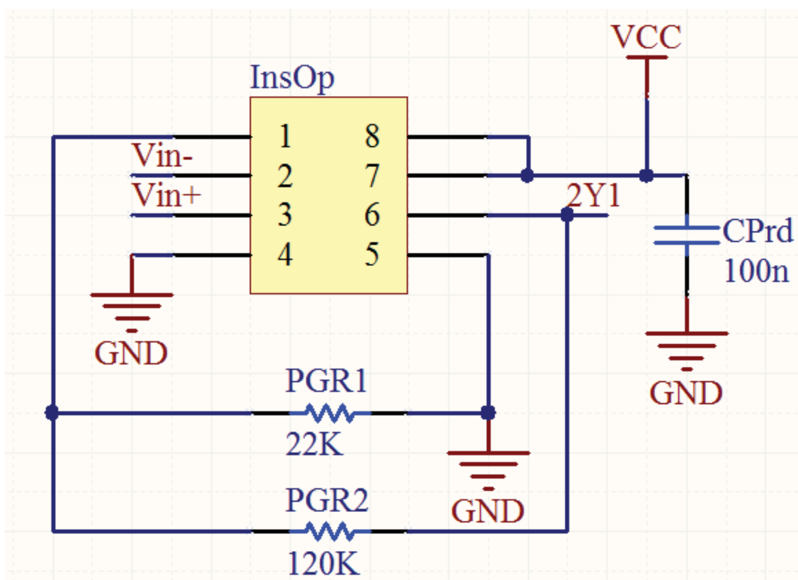


Figure 14: Configuration of Instrumentation Amplifier

As the full scale output was only 60mV the small differential voltage was amplified for better use with the WSN802G ADC. The gain of the instrumentation amplifier was set by the external resistors PGR1 and PGR2 to obtain the desired gain value (3.5.1).

$$G = 5 + 5\left(\frac{PGR2}{PGR1}\right) \quad \textbf{(3.5.1)}$$

Measurements logged for pressure within an enclosed hydroponic area can be seen over an approximately 24 hour period (Figure 15).

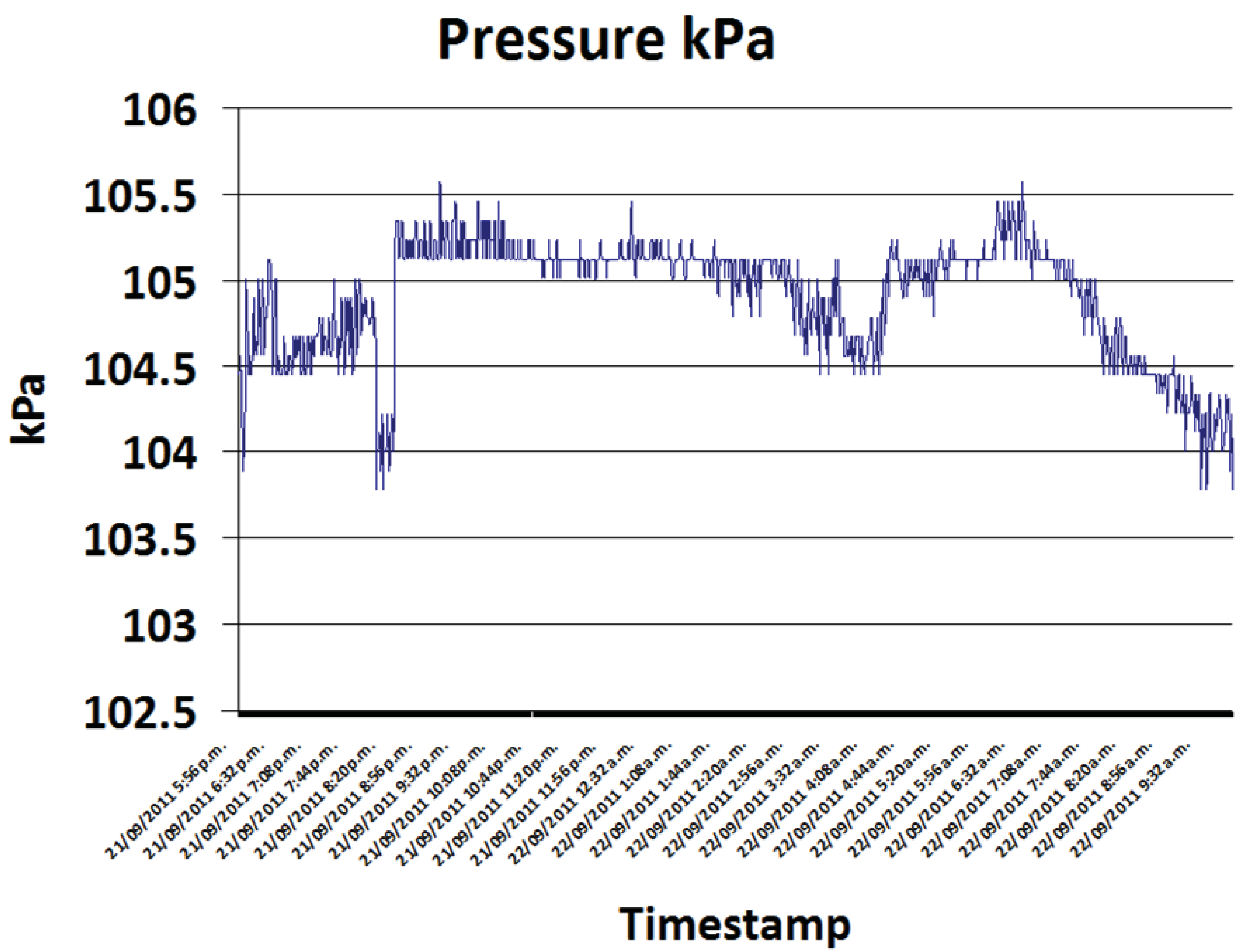


Figure 15: Logged Data for NPP-301 NovaSensor Pressure Sensor

3.6. VG400-LV'S CHARACTERISTICS AND CONSTRUCTION

The VG400-LV sensor (Figure 16) is part of the VEGETRONIX's family of sensors [31] where it can be used to measure soil moisture and water level. This sensor can be used to provide low power consumption and low cost operation. The VG400-LV probe consists of 3 wires: Ground, V_{DD} and V_{Out}. Where V_{DD} is the input voltage which can be between 2V to 20V in order to operate and output a voltage range between 0 to 1.8V. This voltage output is in relation to the moisture content in the soil or water level adjacent to the probe.

These voltage characteristics make it very easy and convenient for ADC interfacing applications. Additionally the VG400-LV is insensitive to water salinity and does not corrode over time as probes based on other technologies do[31]. This makes it a good device for a WSN monitoring system, where an application needing minimal attention and maintenance is sought after.

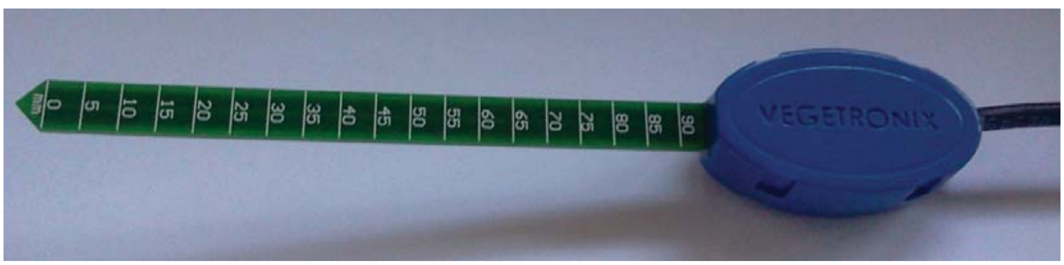


Figure 16: VEGETRONIX VG400-LV Sensor

VG400-LV's key features [31] are:

- Extreme low cost
- Not conductivity based
- Insensitive to salinity
- Probe does not corrode over time
- Rugged design for long term use and small size
- Consumes less than 600uA for very low power operation
- Precise measurement
- Measures volumetric water content (VWC) or gravimetric water content (GWC)

- Output voltage is proportional to moisture level
- Wide supply voltage range
- Can be buried and is water proof

3.6.1. Soil Moisture Testing

Volumetric water content (VWC) is a numerical measure of soil moisture. It is the ratio of water to soil volume. To work out the volumetric water content, various tests were performed with soil to acquire the relationship between VWC and voltage output.

Tools used for measurement of soil moisture (Figure 17):

- A VG400-LV sensor probe from Vegetronix
- A multimeter to measure probe voltage
- 10 containers
- Measuring cups and scales
- The soil which was to be tested
- Power supply

Figure 17: Tools used for Obtaining Relationship of Voltage Output for VWC in Potting Mix for VG400-LV Sensor

3.6.1.1. Procedure for Obtaining VWC for particular Soil Types

- The soil to be tested was dried out at 180C for 24 hours. The soil was stirred periodically. This was done so that all moisture present in the soil was removed to get accurate measurements.
- Measuring cups were used to obtain a quantity of soil based on volume. Efforts were made to make sure the soil was homogeneous and compacted as it was measured. This soil was then filled in each of the containers with sufficient soil so the VG400-LV sensor probe could be fully inserted. Once measurements had been made for the volume of soil, the containers were weighed to make sure all containers had the same weight. As the soil was homogeneous, then equal volumes had equal weight.
- Measured quantities of water were added to each of the 10 containers that had dry soil. For example, for 5% VWC, for 5 cups of soil used 0.25 cups of water were added. A scale was employed to measure the water, to make measuring more accurate.
- The soil samples were mixed, covered and set aside for a few hours for the water to distribute evenly in each sample.
- The VG400-LV sensor was then inserted into each sample (Figure 18) making sure the soil was compact and the sensor probe fully inserted and in good contact with the soil. A multimeter was used to record the voltage reading for each of the samples in order to graph the VWC for each sample as a function of probe voltage (Figure 19).

Figure 18: VG400-LV Sensor Inserted into Soil for Soil Moisture Measurement

It was noticed that as more water was added to the soil a point was reached where the water and soil no longer mixed evenly. The water would immediately separate to the bottom of the soil. The point at which this happens is the hold capacity of the soil, where the water-holding capacity is controlled primarily by soil texture and organic matter [32]. The holding capacity for the potting mix seemed to be around 50% VWC. No further VWC measurements beyond the holding capacity of the soil were taken.

The sensor measures the dielectric constant of the soil using transmission line technique and its output voltage is polynomially proportional to the moisture content in the soil [33]. The relationship between sensor output voltage and the moisture content in the soil can be expressed using the following equation (3.6.1):

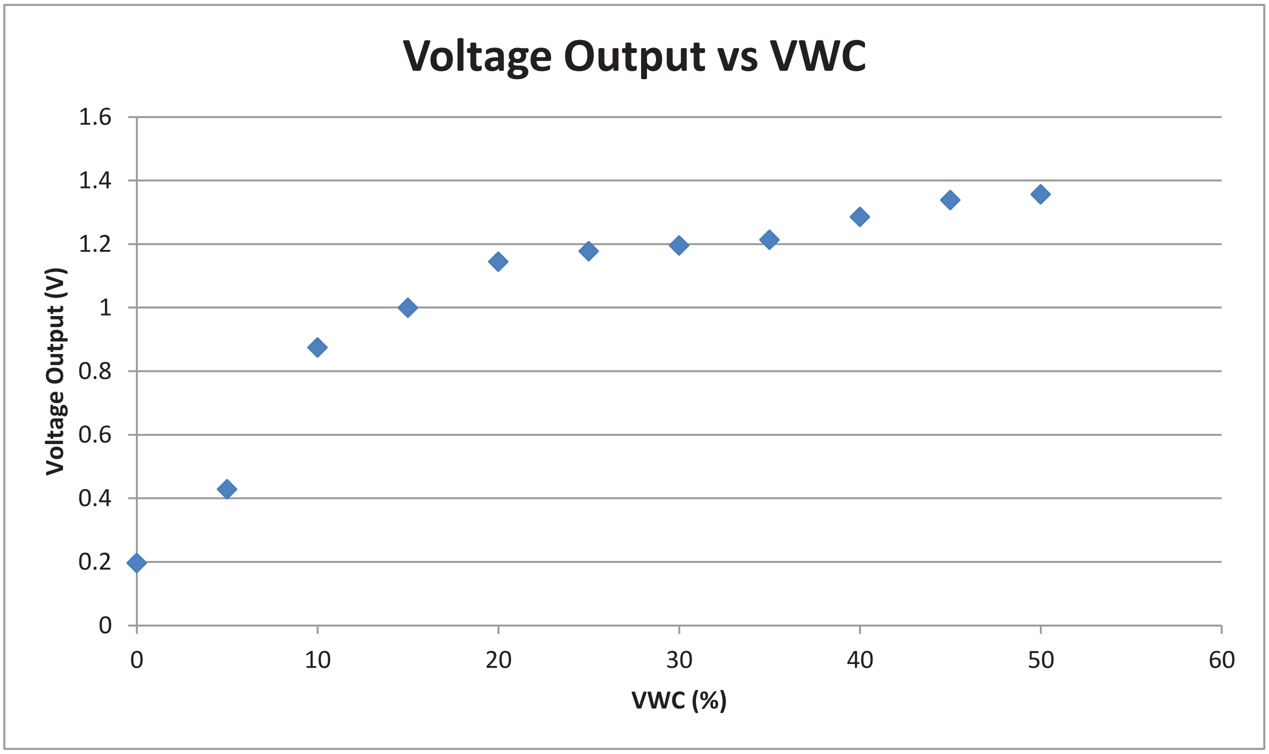


Figure 19: Plot of VG400-LV Soil Moisture Sensor Voltage Outputs for Different VWC

$$VWC(\%) = 53.047\mathrm{V_{OUT}}^{3} - 64.278\,\mathrm{V_{OUT}}^{2} + 25.516\,\mathrm{V_{OUT}} \qquad (3.6.1)$$

Where:

- VWC is the volumetric water content of soil in percentage
- Vout is in V the output voltage of the sensor

Measurements logged for soil moisture within an enclosed greenhouse can be seen over a 10 Day period (Figure 20).

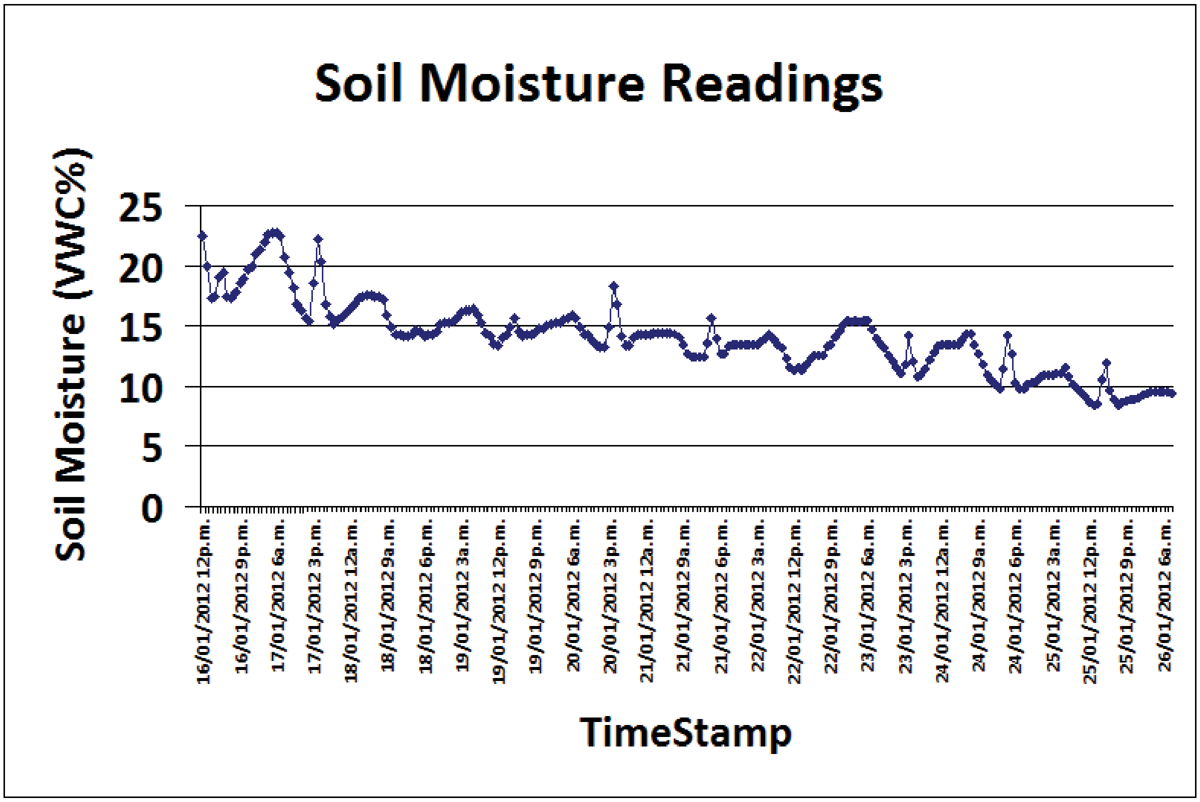


Figure 20: Soil Moisture Readings over a 10 Day Period

3.6.2. Water Level Testing

Water level measurements in mm adjacent to the probe are a numerical measure of interest. It is the height of the water in relation to the tip of the probe. Various tests were performed within the lab to work out the water level measurements in order to acquire the relationship between water level and voltage output.

Tools used for water level testing (Figure 17):

- A VG400-LV moisture sensor probe from Vegetronix.
- A multimeter to measure probe voltage.
- A clamp and stand
- Beaker

- Suction pipette

3.6.2.1. Procedure for Obtaining Water Level

- VG400-LV sensor probe was secured firmly in the clamp and stand. The probe was pointed downwards into an empty beaker.
- Using the suction pipette, water was gradually added to each graduation marked on the VG400-LV.
- The multimeter was used to measure the voltage output at all the different water levels marked on the probe.

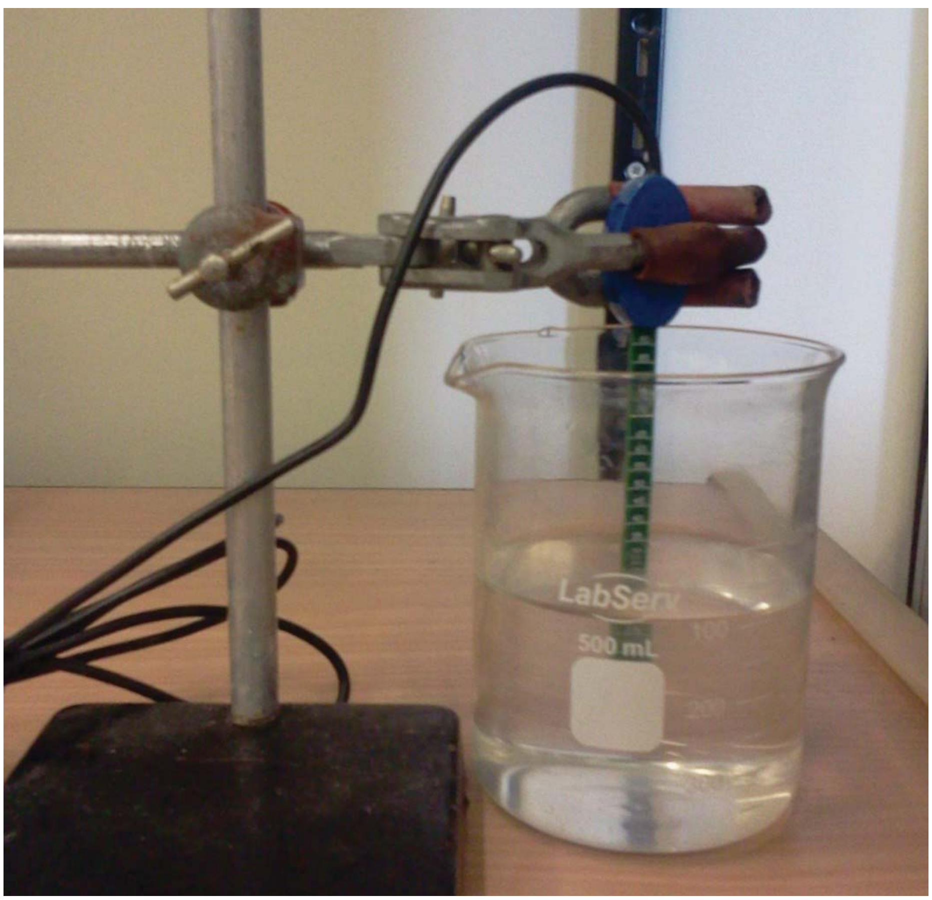


Figure 21: VG400-LV Sensor Inserted into Beaker for Water Level Measurement

The sensor measures the dielectric constant of the water using transmission line technique and its output voltage is linearly proportional to the water level along the probe

[33]. The relationship between sensor output voltage and the water level adjacent to the probe can be expressed using the following equation (3.6.2):

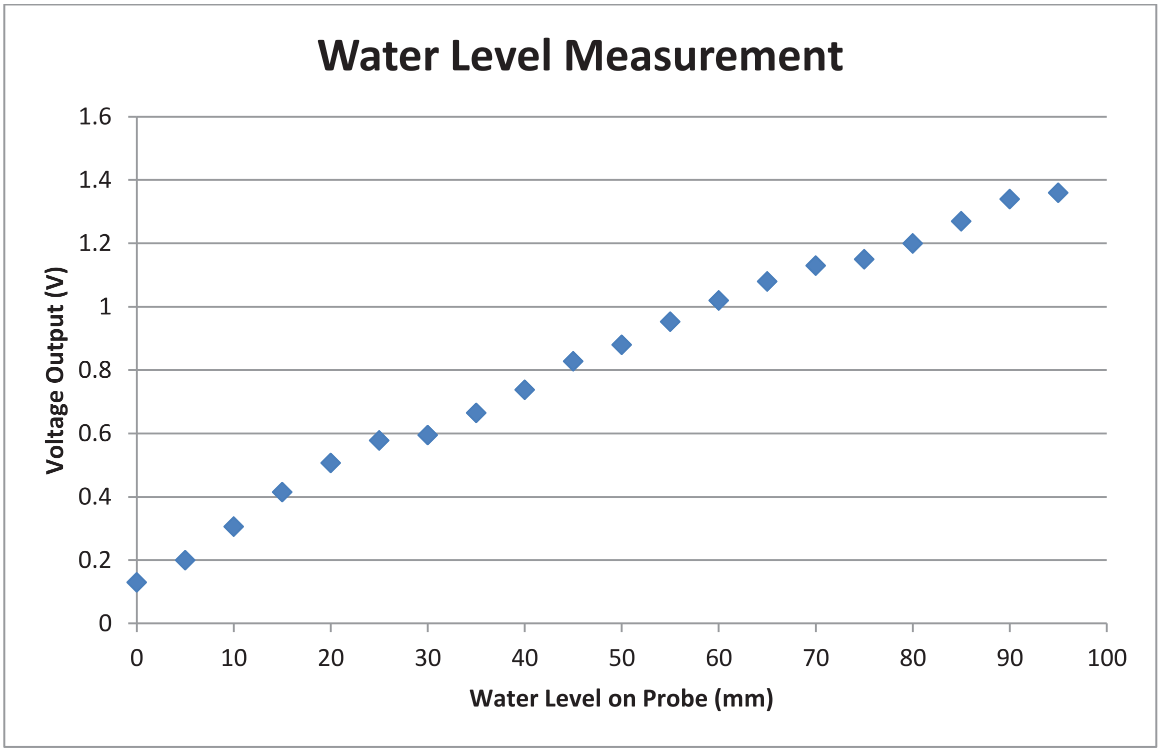


Figure 22: Plot of VG400-LV Voltage Outputs for Different Water Level

$$WaterLevel(mm) = 77.025V_{OUT} - 15.449 \qquad \textbf{(3.6.2)}$$

Where:

- Water level is in mm and adjacent to the measurement attached on probe
- Vout is in V the output voltage of the sensor

Measurements logged for water level readings within an enclosed hydroponic area can be seen over an approximately 10 Day period (Figure 23).

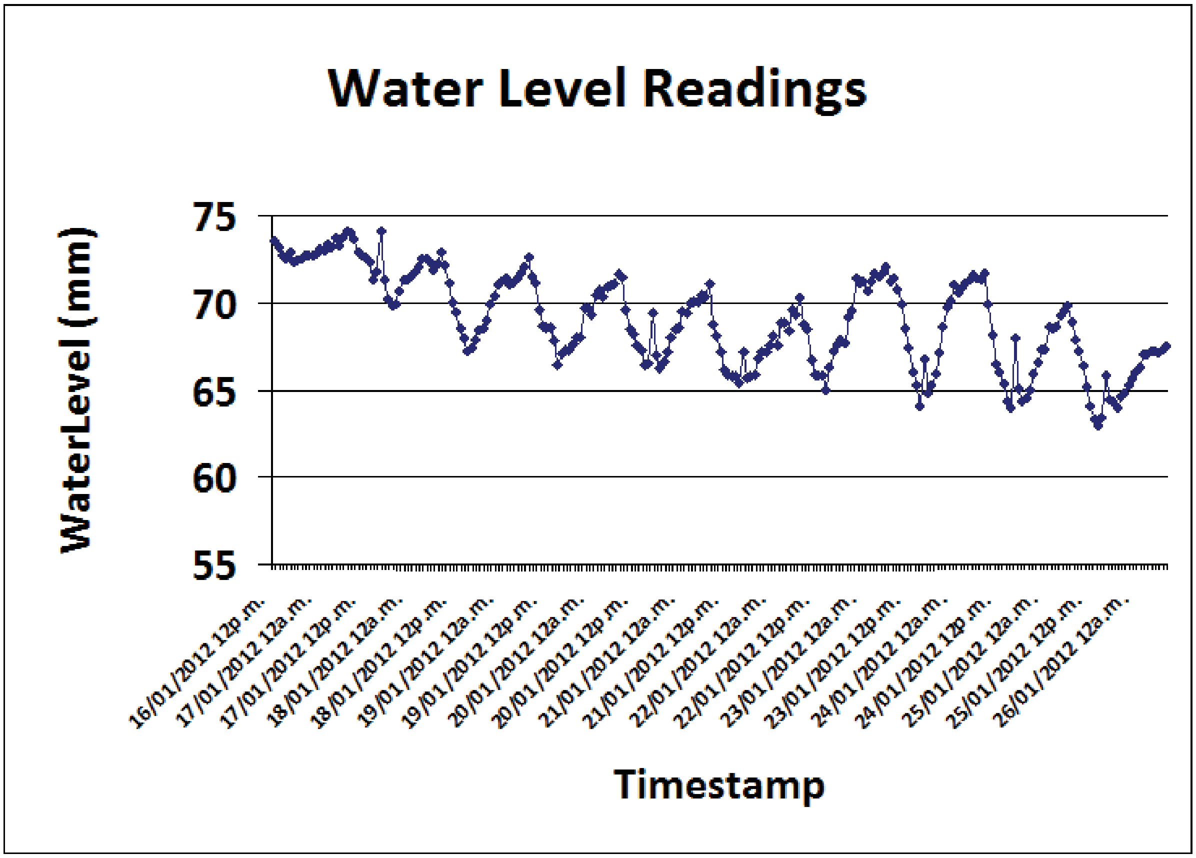


Figure 23: Water Level Readings over a 10 Day Period

3.7. NITRATE SENSOR CHARACTERISTICS AND CONSTRUCTION

3.7.1. Sensor Developers

Various Planar Electromagnetic Sensors research work had been and is still currently being conducted under the School of Engineering and Advanced Technology (SEAT). This has been fabricated and tested for various applications. Of interest to the project is the novel planar electromagnetic sensors for detection of nitrates and contamination in natural water sources [34][35]. It is developed by Mohd Amri Md Yunus, Professor Dr. Subhas Chandra Mukhopadhyay, and Dr. Gourab Sen Gupta where the sensor is based on a combination of meander and interdigital planar electromagnetic sensors for monitoring the level of contamination in water sources. They have performed a series of experiments [36] to determine the sensors characteristics and to observe the sensor response to materials involving distilled water and nitrates solutions of different concentrations.

3.7.2. Sensor Design

The sensor selected for use in the project was designed using Altium Designer 6 and was fabricated using a simple printed circuit board (PCB) fabrication technology [35]. The figure below (Figure 24) obtained from “A New Planar Electromagnetic Sensor for Quality Monitoring of Water from Natural Sources” [36] illustrates the schematic diagram of the sensor used for the project.

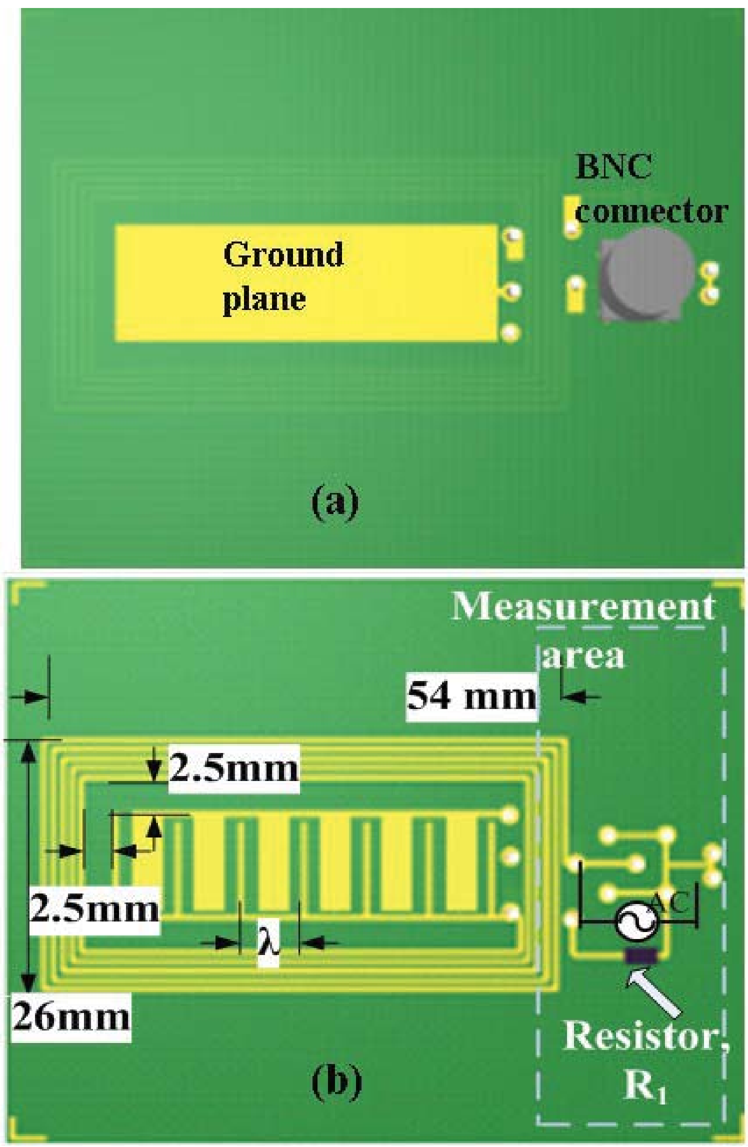


Figure 24: (a) Schematic Diagram of Sensor: Top Layer (b) Schematic Diagram of Sensor: Bottom Layer

3.7.3. Investigation into Integrating Nitrate Sensor

3.7.3.1. Theory behind Nitrate Sensor

Investigation into integrating a Novel Planar Electromagnetic Sensor was conducted. As illustrated in the following (Figure 25) the equivalent circuit of the sensor [36][35] is shown connected to a function generator and R1 denotes the series surface mount resistor used.

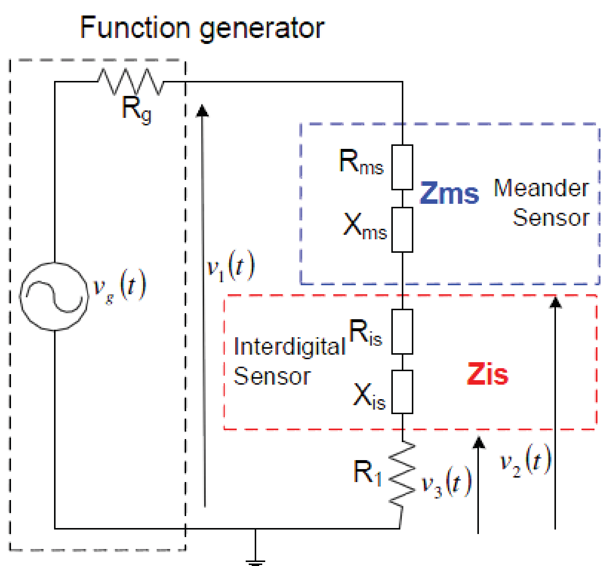


Figure 25: An Electrical Equivalent Circuit of the Sensors Connected in Series

The sensor values for the real and imaginary components can be calculated [36]:

$$Zsensor = \frac{V_1}{i_r} \angle \theta \qquad \textbf{(3.7.1)}$$

$$i_r = \frac{V_3}{R_1} \qquad \textbf{(3.7.2)}$$

$$Zsensor = \frac{V_1}{V_3} . R_1 \angle \theta \qquad \textbf{(3.7.3)}$$

$$R_{TSample} = Zsensor.\cos(\theta) - R_1 \qquad \textbf{(3.7.4)}$$

$$X_{TSample} = Zsensor.\sin(\theta) \qquad \textbf{(3.7.5)}$$

Where θ is the phase difference between $v_1(t)$ with $v_3(t)$ and $\frac{V_1}{V_3}$ used for $Zsensor$ represents the gain of V_1 and V_3

The water sensor uses the values of the $R_{TSample}$ and $X_{TSample}$ along with the equivalent values in distilled water in order to work out the real part sensitivity and imaginary part sensitivity. By using the sensitivity values it is possible to evaluate the properties of water and assess the safety of the water being tested.

Tests were performed with the sensor design team on various water samples (Table 1). The test objective was to measure the contamination in water samples taken from different locations in New Zealand.

Table 1: Water Samples Tested using Nitrate Sensor [19]

Sample
570-1,Matakana raw
570-2,Matakana magnetic circle tank
570-3,IPL Mixed water UV
570-4, Edgecumbe raw
570-5, McCains D119 raw
570-6, Matakana raw2
570-7, McCains treated
570-8, Tauranga tapwater
570-9, Techical water system potable
570-10, Edgecumbe magnetic treatment

Obtaining the real part sensitivity and imaginary part sensitivity allows for detection of contamination in water samples. The sensitivity values calculated for the water samples as shown in (Figure 26) and (Figure 27). Samples of 570-1 to 570-7 should never be consumed and the most contaminated water sample is 570-7; water samples seen as safe for consumption are, 570-8, 570-9 and 570-10.

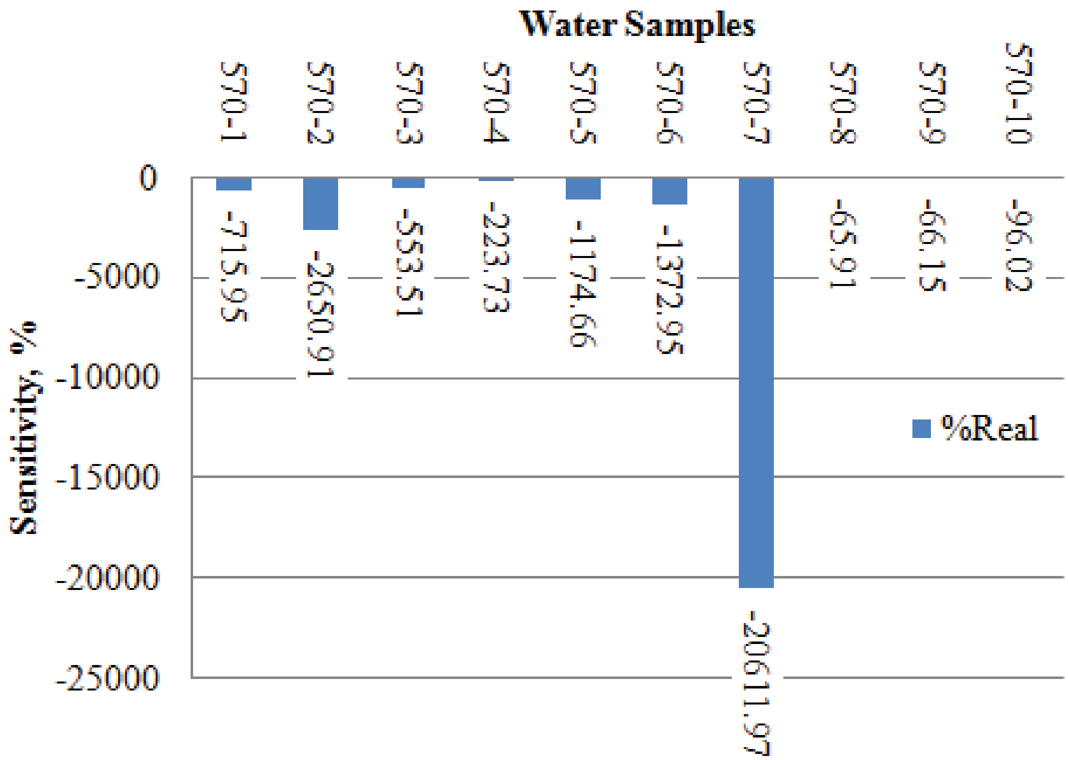


Figure 26: Real Part Sensitivity to the Water Samples [19]

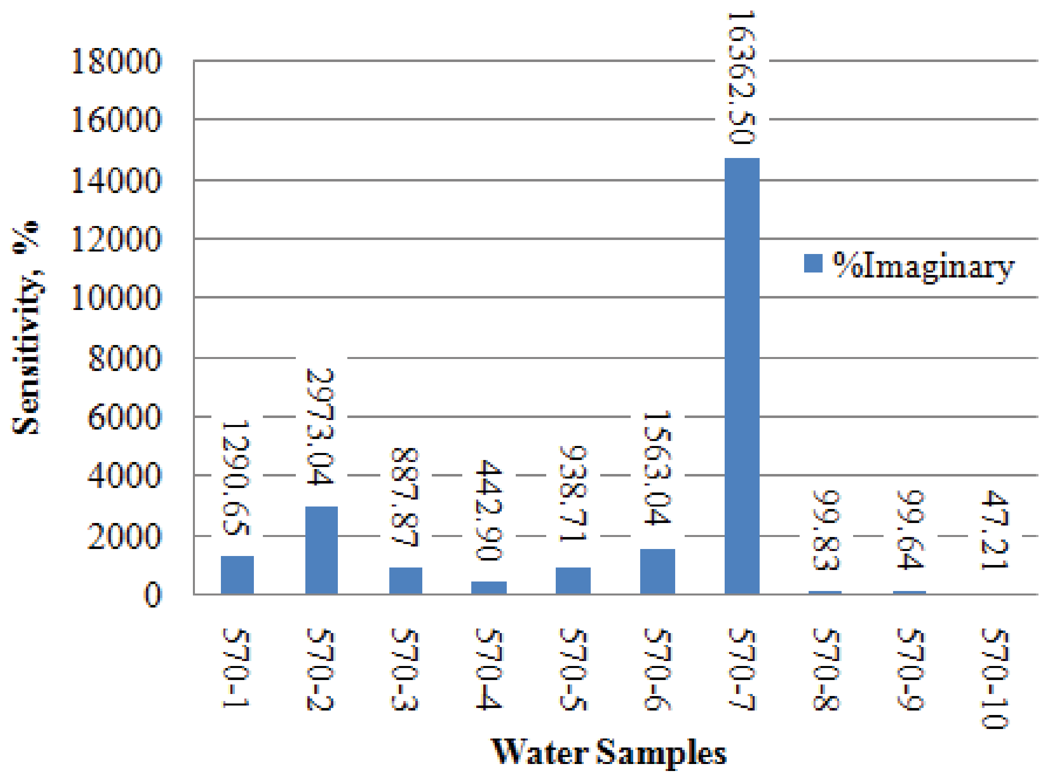


Figure 27: Imaginary Part Sensitivity to the Water Samples [19]

3.7.3.2. Initial Design for Nitrate Detection System

As discussed previously the sensor uses the phase difference and gain in order to evaluate properties of water. One of the major components of a nitrate detection system is the method of measuring the gain and phase. (Figure 28) is a block diagram of the initial design for the various parts of the systems.

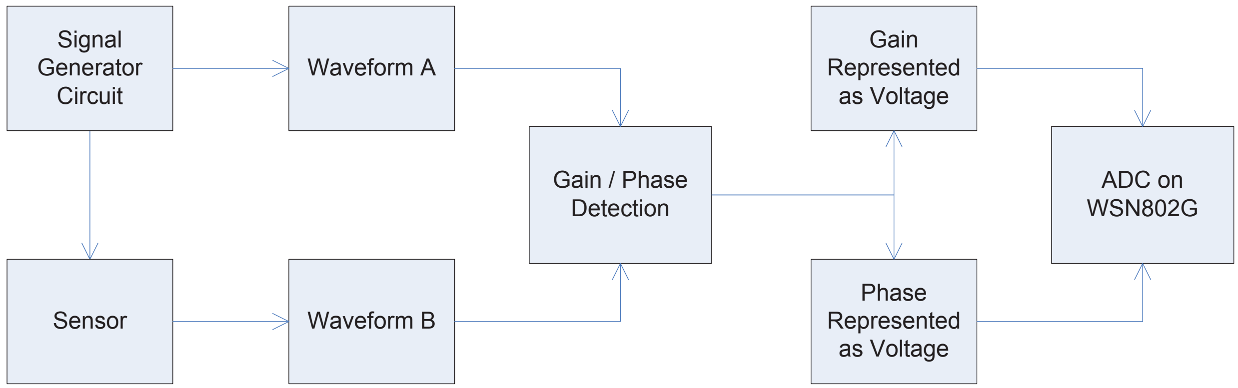


Figure 28: Block Diagram of the Project's Initial Design for Various Systems and their Desired Layout

The various systems such as the signal generator circuit, and Gain/Phase detection are described and discussed in more detail further on. The initial system design had Waveform A as the original output of the signal generator and Waveform B as the output of the sensor. These two waveforms required a connection to a Gain/Phase detection system that provides a voltage representation of Gain and Phase. This voltage representation is then passed on so it could be used by, and processed by, the WSN802G's ADCs. Once the WSN802G has a resulting value for Gain and Phase it would then be able to output the results wirelessly back to the server.

3.7.3.3. The Signal Generator Circuit

The nitrate detection system required a function generator for use with the sensor and investigated whether the use of the XR2206, a monolithic function generator IC, was selected for use with the sensor [37]. The XR2206 is able to produce high quality sine, square, triangle, ramp, and pulse waveforms. The sine output waveform is the required waveform for use with the sensor. The XR2206 can adjust both amplitude and frequency of output waveform, where the frequency of operation for the XR2206 can be selected to be over a range of 0.01Hz to about 1MHz.

Table 2: The Pin Description from the XR-2206 Datasheet [37]

PIN DESCRIPTION

Pin #	Symbol	Type	Description
1	AMSI	I	**Amplitude Modulating Signal Input.**
2	STO	O	**Sine or Triangle Wave Output.**
3	MO	O	**Multiplier Output.**
4	V_{CC}		**Positive Power Supply.**
5	TC1	I	**Timing Capacitor Input.**
6	TC2	I	**Timing Capacitor Input.**
7	TR1	O	**Timing Resistor 1 Output.**
8	TR2	O	**Timing Resistor 2 Output.**
9	FSKI	I	**Frequency Shift Keying Input.**
10	BIAS	O	**Internal Voltage Reference.**
11	SYNCO	O	**Sync Output.** This output is a open collector and needs a pull up resistor to V_{CC}.
12	GND		**Ground pin.**
13	WAVEA1	I	**Wave Form Adjust Input 1.**
14	WAVEA2	I	**Wave Form Adjust Input 2.**
15	SYMA1	I	**Wave Symetry Adjust 1.**
16	SYMA2	I	**Wave Symetry Adjust 2.**

The frequency oscillation (fo) of the XR-2206, is determined by the timing capacitor, C, across Pin 5 and 6, and by the timing resistor, R, connected to Pin 7 (Table 2). The value of frequency (fo) is given by:

$$f_0 = \frac{1}{RC}\ Hz$$

Table 3: The XR2206 Datasheet Oscillator Section [37]

Oscillator Section								
Max. Operating Frequency	**0.5**	1		0.5	1		MHz	C = 1000pF, R_1 = 1kΩ
Lowest Practical Frequency		0.01			0.01		Hz	C = 50μF, R_1 = 2MΩ
Sweep Range	1000:1	2000:1			2000:1		$f_H = f_L$	f_H @ R_1 = 1kΩ f_L @ R_1 = 2MΩ

From the datasheet we can also find the minimum and maximum values for both the timing capacitor and resistor. The timing resistor can be between 1k Ohm and 2M Ohm (Table 3) and likewise the timing capacitor can be between 0.001uF (or 1nF) and 100uF.

The XR2206 has a wide supply range, 10V to 26V. Depending on the voltage supply provided to the multiplier output Pin 3, the amplitude or maximum peak-to-peak voltage of the output waveform is established. Figure 29 shows the schematic design created in

Altium Designer for the XR2206 signal generator system and (Figure 30) PCB design of the system.

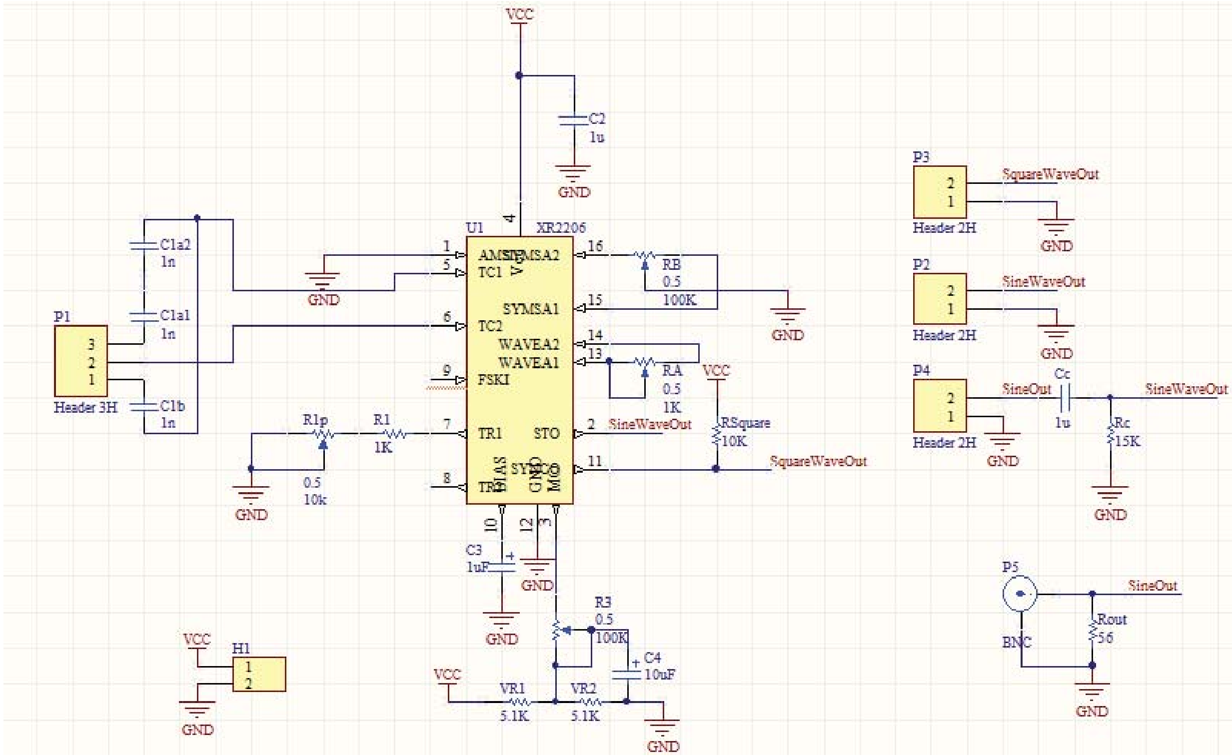


Figure 29: The XR2206 Signal Generator Circuit Schematic

The potentiometer R1p and R1 represent the timing resistor, R, connected to Pin 7 and the changing value adjusts the frequency of the oscillation. Adjusting P1 and the pins that are connected adjusts the values of timing capacitor, C, across Pin 5 and 6. The following values are given for the different selection of P1; if pins 1 and 2 are linked, then the Value of C = 1nF, where as if pins 2 and 3 are linked, C = 0.5nF.

$$f_0 = \frac{1}{RC}\ Hz$$

The system has two C values, selectable by P1, and adjustable resistors (potentiometers) that can be adjusted from 1kOhm to about 10kOhm. The values selected approximately cover the frequency ranges of 100kHz to 1MHz by adjusting the potentiometer and switching pins for P1. It is possible, if required, to have the system achieve a 1 Hz to 1 MHz output by changing the values of R and C used and setting them closer to the calculated 1uF capacitor and 1MOhm resistor for 1Hz.

The potentiometer R3 is connected to the multiplier output Pin 3 where adjusting the value of R3 adjusted the peak-to-peak voltage of the outputted sine wave. However, it was found that the maximum amplitude the sine wave could obtain was also dependent upon frequency - where lower frequency sine waves could obtain higher maximum peak-to-peak voltage, than higher frequency sine wave. The other two potentiometers RA and RB are for wave symmetry adjustment where the potentiometer are used to make sure the wave forms are symmetrical and is a sine waveform rather than triangular.

The capacitor Cc and resistor Rc are in place to provide capacitive coupling or AC coupling. This is used to get rid of the DC offset from output before it is used by the sensor. It works on the basis that the coupling capacitor allows the ac signal to be passed on while keeping the DC part isolated.

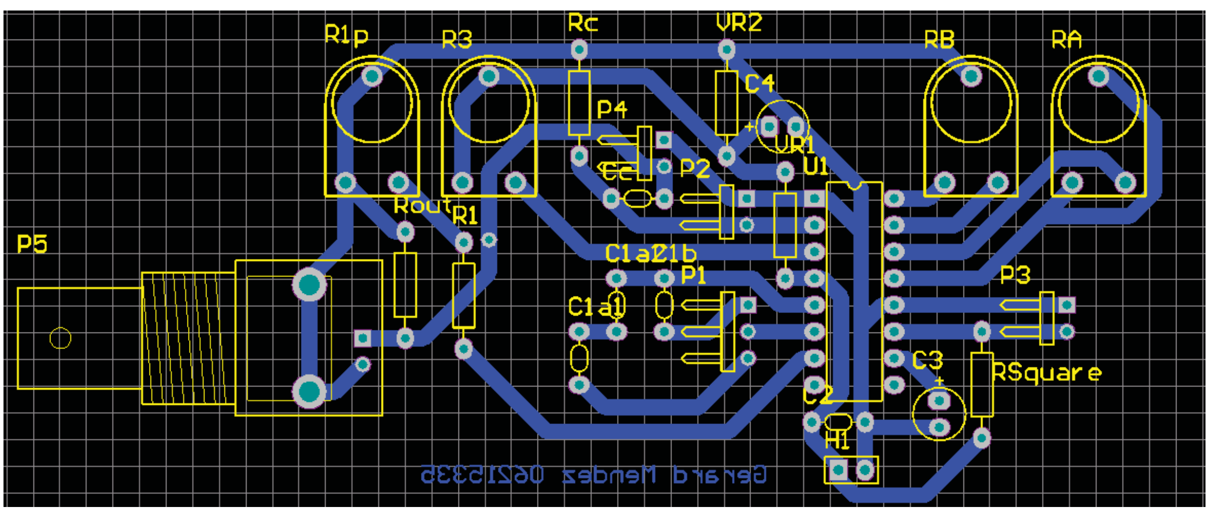


Figure 30: The XR2206 Signal Generator Circuit PCB Design

As discussed previously The XR2206 has a wide supply range, 10V to 26V and depending on the voltage supply provided to the multiplier output Pin 3 the amplitude or maximum peak-to-peak voltage of the output waveform is established. (Figure 31) shows the various components of the system and their various resulting effects.

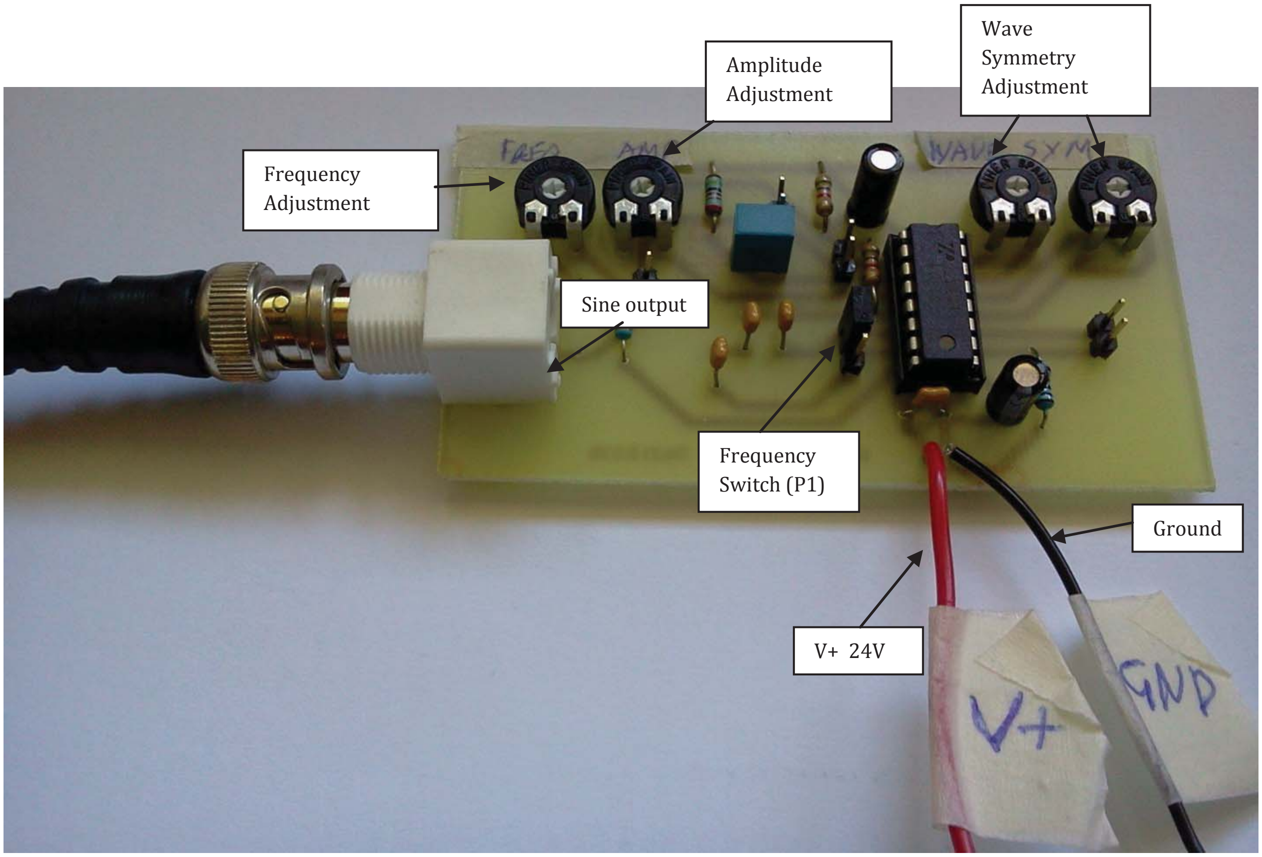


Figure 31: The XR2206 Circuit Image

3.7.3.4. Signal Generator Circuit Output

The following figure shows the signal generator circuit using the XR2206 IC to generate a 100kHz 10Vpp sine wave which is connected to the sensor and display the output. The signal generator circuit is able to provide up to a 1MHz 10Vpp sine wave when using a 24V supply. The value of frequency and amplitude can be adjusted as discussed previously. The following (Figure 32) shows it is possible to get relatively close to 100kHz and 10Vpp using the signal generator circuit.

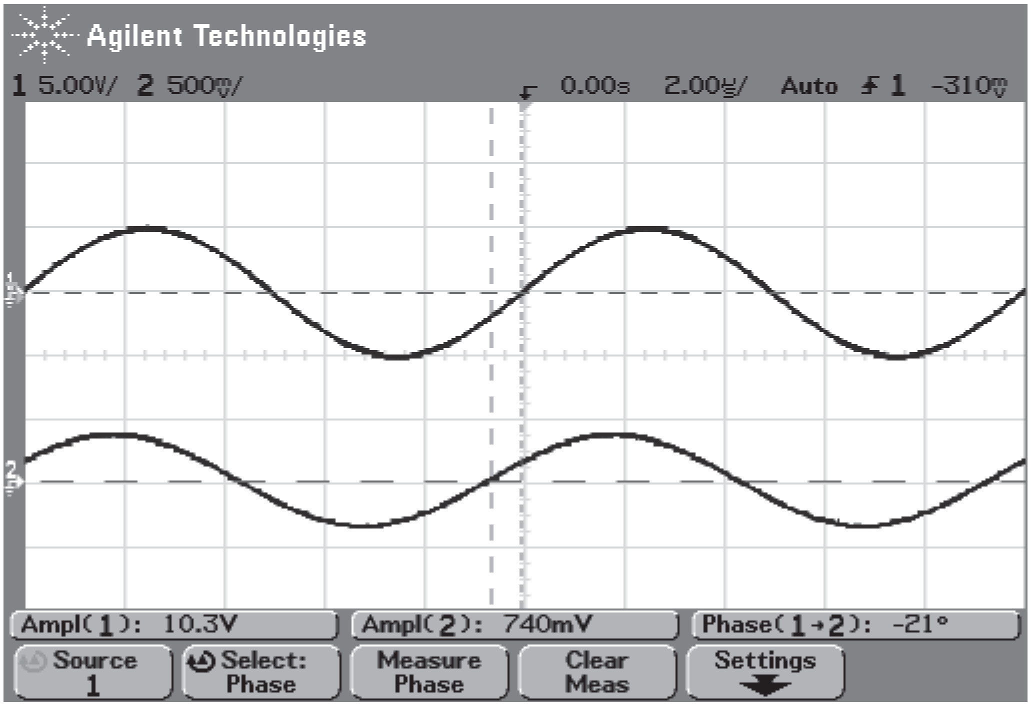


Figure 32: Oscilloscope Reading Signal Generator Circuit Output (1) and Sensor Output (2)

3.7.3.5. Gain and Phase Detection Circuit

Obtaining accurate measurement of the gain (amplitude ratio) and phase difference between the two signals of the signal generator and the sensor output is of key importance and practical significance. The project went about investigating using the AD8302 from Exar in order to quantify and measure the desired values. The AD8302 was chosen in the hope that a simple system would be able to provide gain and phase difference measurement more precisely than a complex circuit, and have the suitable operating frequency range.

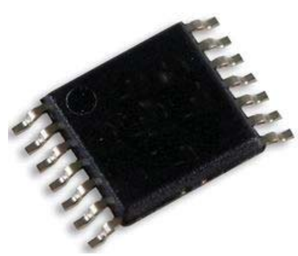


Figure 33: The Surface Mount Device AD8302 Gain Phase Detector [38]

The AD8302 datasheet describes it as a fully integrated system for measuring gain and phase in numerous receiving, transmitting, and instrumentation applications. The AD8302 comprises of a closely matched pair of demodulating logarithmic amplifiers, a precision 1.8V reference voltage output, (Table 4) and analogue output scaling circuits [38]. The AD8302 requires few external components and a single supply of 2.7 V–5.5 V. As described in the following figure from the AD8302 datasheet, the input signals that are ac-coupled can range from –60 dBm to 0 dBm, and from low frequencies (>0) up to 2.7 GHz.

Table 4: The Overall Function and Input Interface from AD8302 Specifications [38]

Parameter	Conditions	Min	Typ	Max	Unit
OVERALL FUNCTION					
Input Frequency Range		>0		2700	MHz
Gain Measurement Range	P_{IN} at INPA, P_{IN} at INPB = −30 dBm		±30		dB
Phase Measurement Range	ϕ_{IN} at INPA > ϕ_{IN} at INPB		±90		Degree
Reference Voltage Output	Pin VREF, −40°C ≤ T_A ≤ +85°C	1.72	1.8	1.88	V
INPUT INTERFACE	Pins INPA and INPB				
Input Simplified Equivalent Circuit	To AC Ground, f ≤ 500 MHz		3‖2		kΩ‖pF
Input Voltage Range	AC-Coupled (0 dBV = 1 V rms)	−73		−13	dBV
	re: 50 Ω	−60		0	dBm
Center of Input Dynamic Range			−43		dBV
			−30		dBm

The basic theory behind the AD8302 as described in the datasheet [38] explains that the AD8302 takes the difference in the output of two identical log amps, where each is driven by signals of similar waveforms but at different levels, the resulting output is VMAG. The output of the final stage of a log amp is a fully limited signal over most of the input dynamic range. The limited outputs from the log amps drive an exclusive-OR style digital phase detector to provide VPHS. The following figure illustrates the general structure of the AD8302.

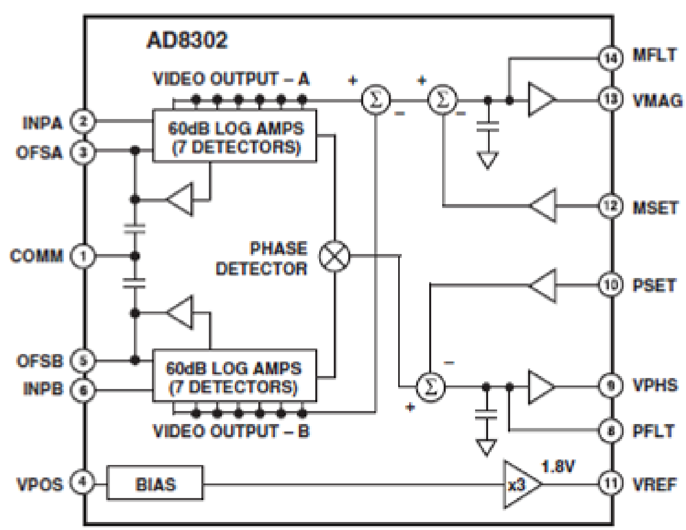


Figure 34: The General Structure of AD8302 from Datasheet [38]

(Table 5) illustrates the output specifications for magnitude and phase from the AD8302 datasheet [38]. The AD8302 can provide accurate measurements of either gain or loss over a ±30 dB range scaled to 30 mV/dB. Thus, it is possible to calculate value of gain in dB by taking the output voltage of VMAG and performing the following calculation:

$$((Voltage_{Out}) - 900) \div 30 \qquad \textbf{(3.7.6)}$$

Where the unit for $Voltage_{Out}$ is in mV

I.e. if voltage output is equal to 1.8V (1800-900) ÷ 30 = 30dB.

Similarly the AD8302 can measure phase over a 0°–180° range scaled to 10 mV/degree where it is possible to calculate value of phase in degrees by taking the output voltage of VPHS and performing the following calculation:

$$((Voltage_{Out}) - 1800) \div (-10) \qquad \textbf{(3.7.7)}$$

Where the unit for $Voltage_{Out}$ is in mV

I.e. if voltage output is equal to 900mV (900-1800) ÷ (-10) = 90̊.

However, the AD8032 can not differentiate between positive or negative phase i.e. +90̊ or -90̊, but this should not cause too many issues in this application

Table 5: The AD8302 Datasheet Specifications for Outputs [38]

MAGNITUDE OUTPUT	Pin VMAG		
Output Voltage Minimum	$20 \times \text{Log}\,(V_{INPA}/V_{INPB}) = -30$ dB	30	mV
Output Voltage Maximum	$20 \times \text{Log}\,(V_{INPA}/V_{INPB}) = +30$ dB	1.8	V
Center Point of Output (MCP)	$V_{INPA} = V_{INPB}$	900	mV
Output Current	Source/Sink	8	mA
Small Signal Envelope Bandwidth	Pin MFLT Open	30	MHz
Slew Rate	40 dB Change, Load 20 pF‖10 kΩ	25	V/µs
Response Time			
Rise Time	Any 20 dB Change, 10%–90%	50	ns
Fall Time	Any 20 dB Change, 90%–10%	60	ns
Settling Time	Full-Scale 60 dB Change, to 1% Settling	300	ns
PHASE OUTPUT	Pin VPHS		
Output Voltage Minimum	Phase Difference 180 Degrees	30	mV
Output Voltage Maximum	Phase Difference 0 Degrees	1.8	V
Phase Center Point	When $\phi_{INPA} = \phi_{INPB} \pm 90°$	900	mV
Output Current Drive	Source/Sink	8	mA
Slew Rate		25	V/µs
Small Signal Envelope Bandwidth		30	MHz
Response Time	Any 15 Degree Change, 10%–90%	40	ns
	120 Degree Change $C_{FILT} = 1$ pF, to 1% Settling	500	ns

In the (Figure 35) schematic diagram it can be seen that the external capacitors are attached to MFLT and PFLT Pins that are the low pass filter terminals for the magnitude and phase output where the input signals are ac-coupled.

The output of the AD8302 is beneficial for use in the WSN system as it should stay around 1.8V max so when inputted into the ADC input on the WSN803G module it is unlikely to exceed the 1.8V that the WSN803G ADC operates at. The AD8302 also provide values that are not less than zero so when attaching to the 10-Bit Analog to Digital Converter (ADC) on the WSN802G there is no requirement to offset any values.

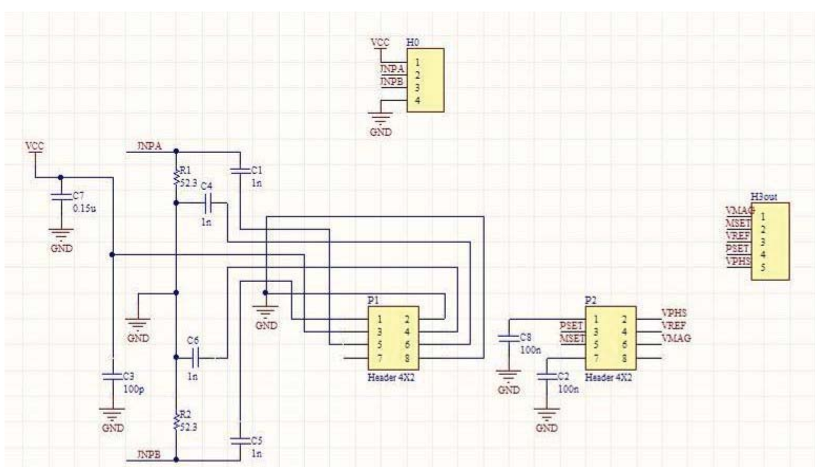


Figure 35: The Schematic for Gain and Phase Detection Circuit that AD8302

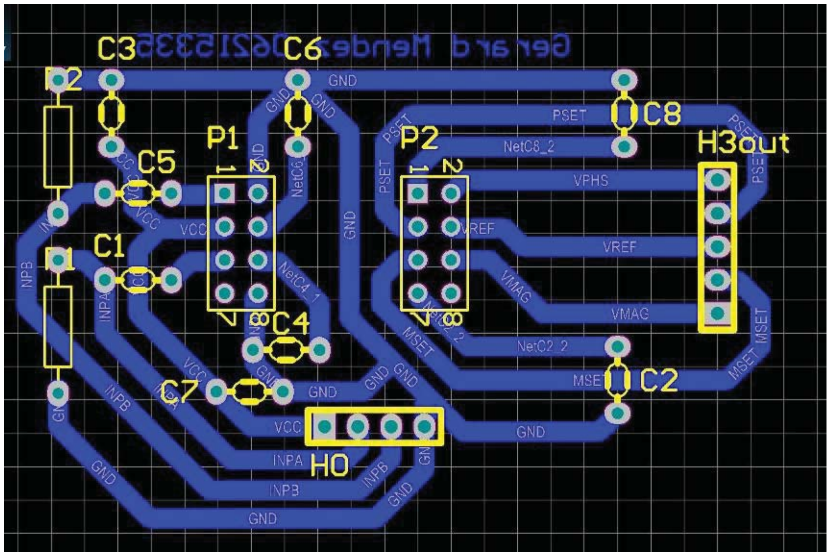


Figure 36: The PCB Design for Gain and Phase Detection Circuit that AD8302

In (Figure 37) it is shown that MSET and VMAG are connected and PSET and VPHS are connected. This is to invoke the default slopes and centre points by having the output pins, VMAG and VPHS, connected directly to the feedback setpoint input pins, MSET and PSET. As described in the AD8302 datasheet [38], the current from the setpoint interface is forced by the integrator to be equal to the signal currents coming from the log amps and phase detector. Illustrated is the AD8302 and adapter plug in which the pins face downwards to fit in to the two 4X2 pin sockets (P1, P2).

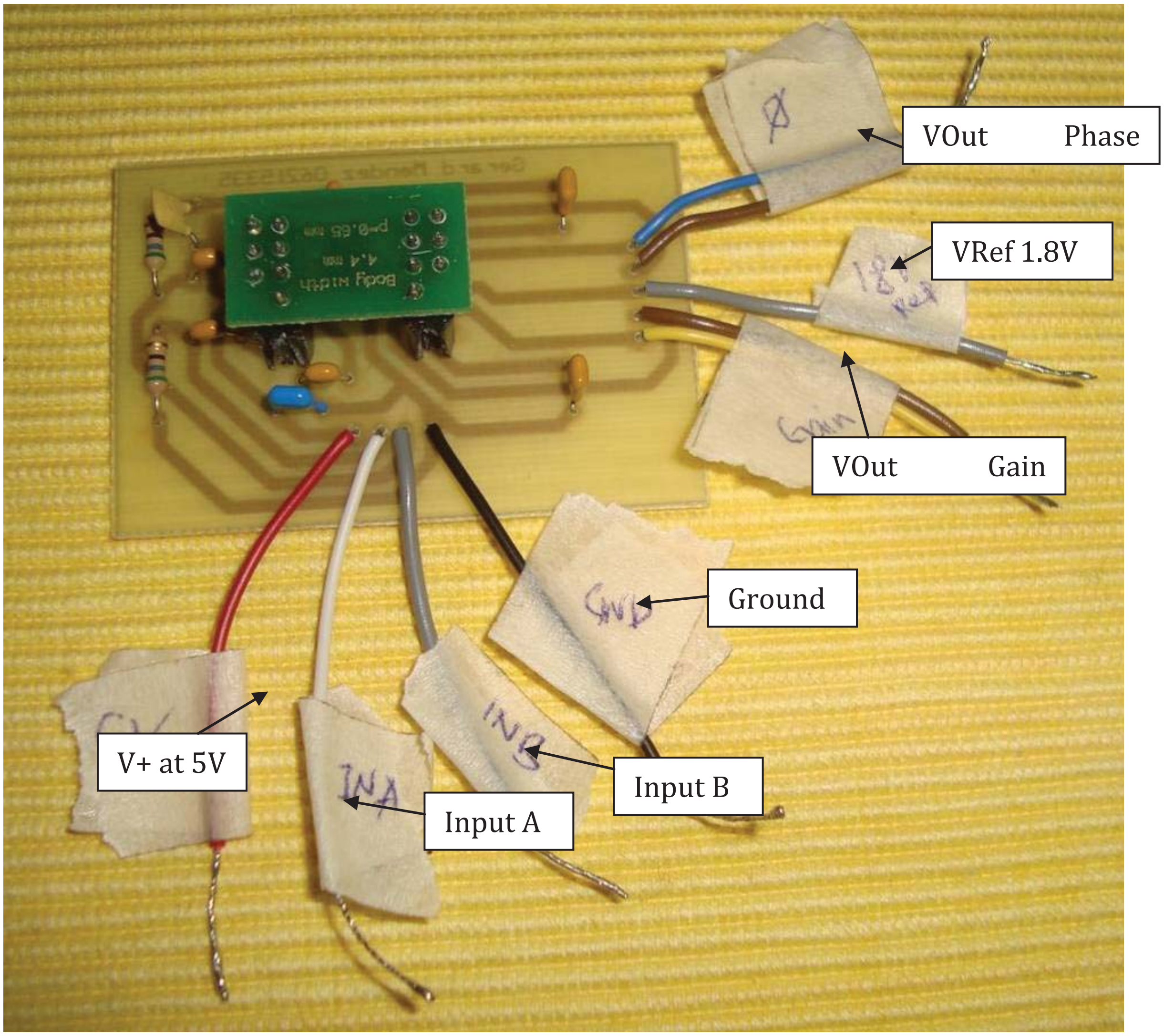


Figure 37: Image of Gain and Phase Detection Circuit with AD8302 and Adapter Attached

3.7.3.6. Phase Detection Output

(Figure 38) displays the experimental results obtained for the Phase detection circuit using the AD8302. Values are measured and plotted where the inputs phases are varied with the use of two function generators running at 0dBm at 100kHz. It can be seen that the measured results appear to match the expected result (Figure 39) from the AD8302 datasheet for phase output vs. input phase difference.

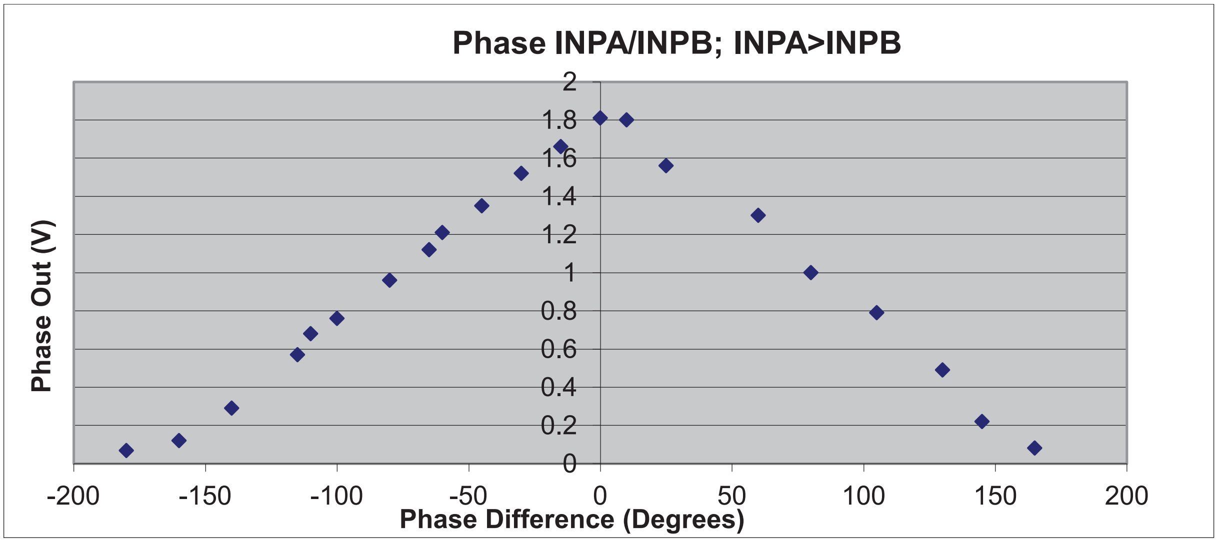
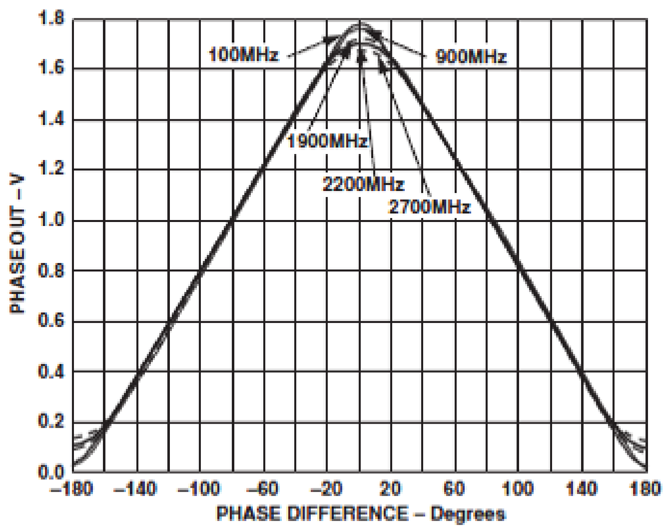


Figure 38: Measured Results for Phase Output vs. Input Phase Difference of AD8302 with Multimeter



TPC 25. Phase Output (VPHS) vs. Input Phase Difference, Input Levels –30 dBm, Frequencies 100 MHz, 900 MHz, 1900 MHz, 2200 MHz, Supply 5 V, 2700 MHz

Figure 39: Phase Output vs. Input Phase Difference from AD8302 Datasheet [38]

(Figure 38) shows that phase detection is fairly accurate and provides similar results to what is expected. As discussed previously the system does not differentiate between positive or negative phase.

3.7.3.7. Gain Detection Output

(Figure 40) displays the experimental results obtained for the gain detection circuit using the AD8302. It plots the expected values and the values measured where the inputs' amplitudes are varied with the use of two function generators running at 100kHz between the ranges of 0dBm and -30dBm. It can be seen that the measured results generally appear to match the expected result from the AD8302 datasheet for magnitude output (VMAG) vs. input level ratio(Gain) except at the magnitude ratios greater than 15dB and less than -15dB where the results no longer appear to be linear. This is somewhat undesirable as calculations will be inconsistent in particular as the value of VMAG exceeds 1.8V at +20dB. However, it can be seen (Figure 41) that the values of the frequencies used in the datasheet are significantly higher than 100kHz.

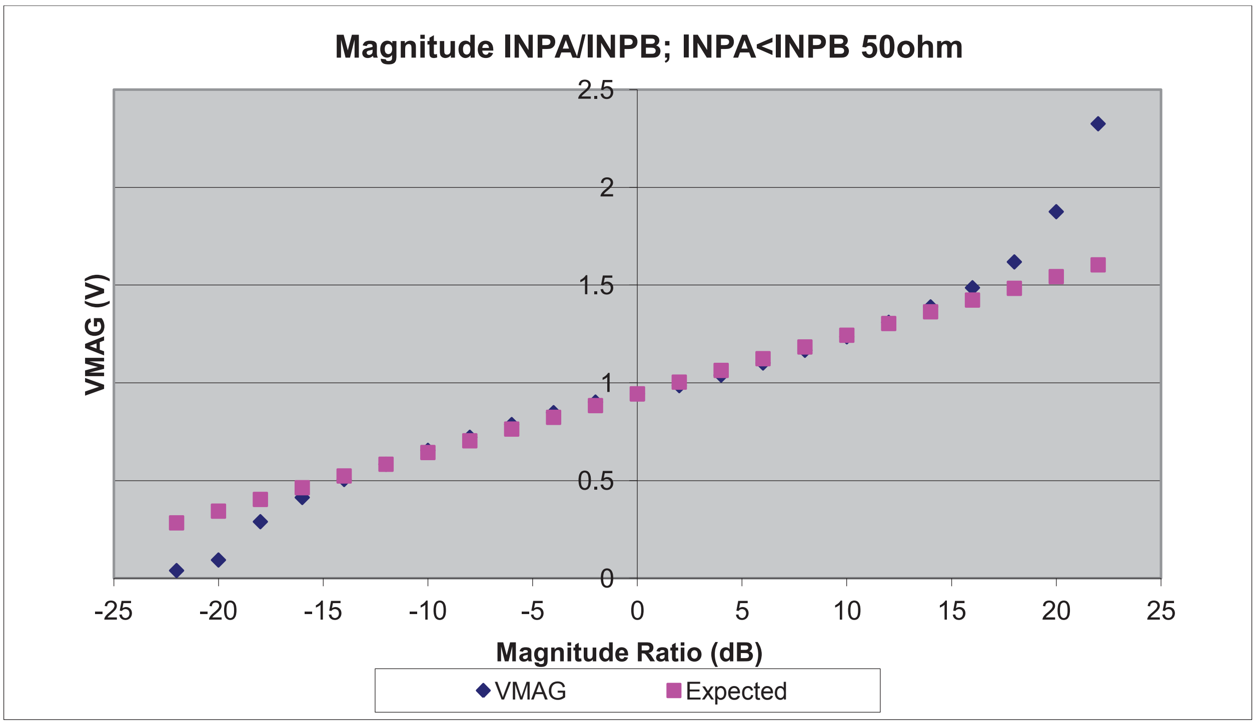
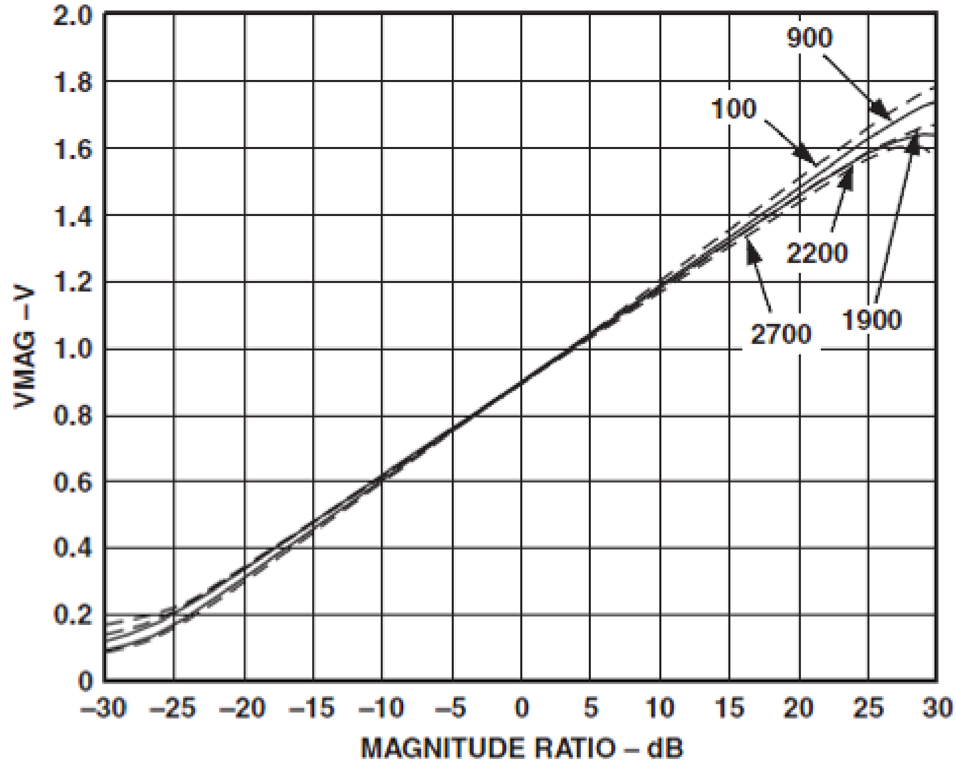


Figure 40: Measured Results for Magnitude Output (VMAG) vs. Input Level Ratio (Gain) with Multimeter



TPC 1. Magnitude Output (VMAG) vs. Input Level Ratio (Gain) V_{INPA}/V_{INPB}, Frequencies 100 MHz, 900 MHz, 1900 MHz, 2200 MHz, 2700 MHz, 25°C, P_{INPB} = –30 dBm,

Figure 41: Magnitude Output (VMAG) vs. Input Level Ratio (Gain) [38]

3.7.3.8. Connecting the Different Parts of the Systems

A key component of the nitrate detection system is based on the AD8302 which is a fully integrated system for measuring either gain or loss over a 30 dB range scaled to 30 mV and phase over 0◦ to 180◦ range [38]. The ac-coupled input signals can range from −60 dBm (316 µVpeak) to 0 dBm (316 mVpeak) in a 50Ω system, from low frequencies up to 2.7 GHz [38]. Issues occurred with the connection of the signal generator and sensor waveforms to the inputs of the gain and phase detection circuit, as they required the input signals to be within the ranges of –60 dBm to 0 dBm. This required the signal generator and sensor waveforms peak-to-peak voltage to be reduced to the correct values. The following schematic (Figure 42) and PCB (Figure 43) construction was investigated in collaboration with the original Novel Planar Sensor creator for the connection circuit for the AD8302.

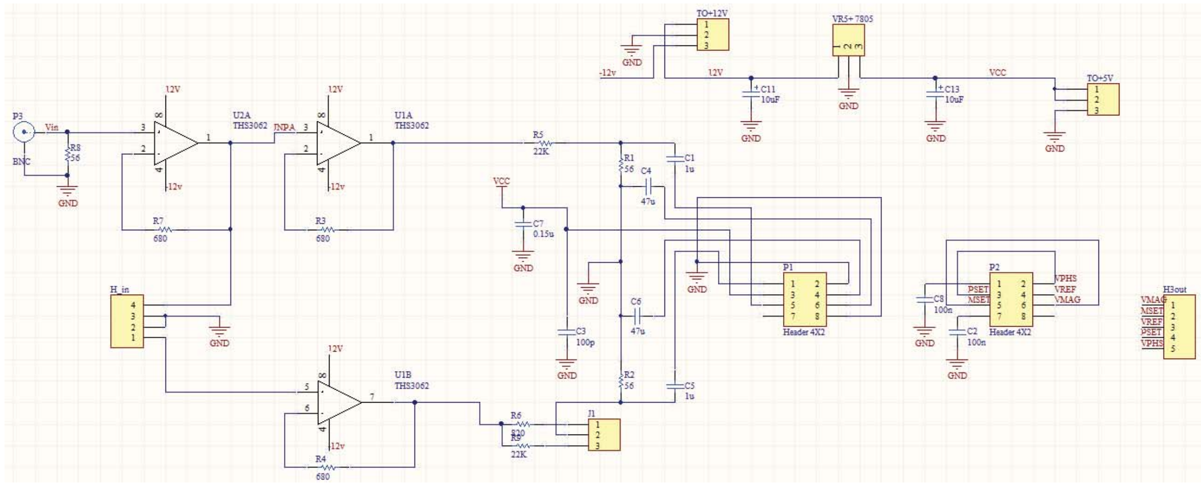


Figure 42: The Schematic for Connection Circuitry between Systems

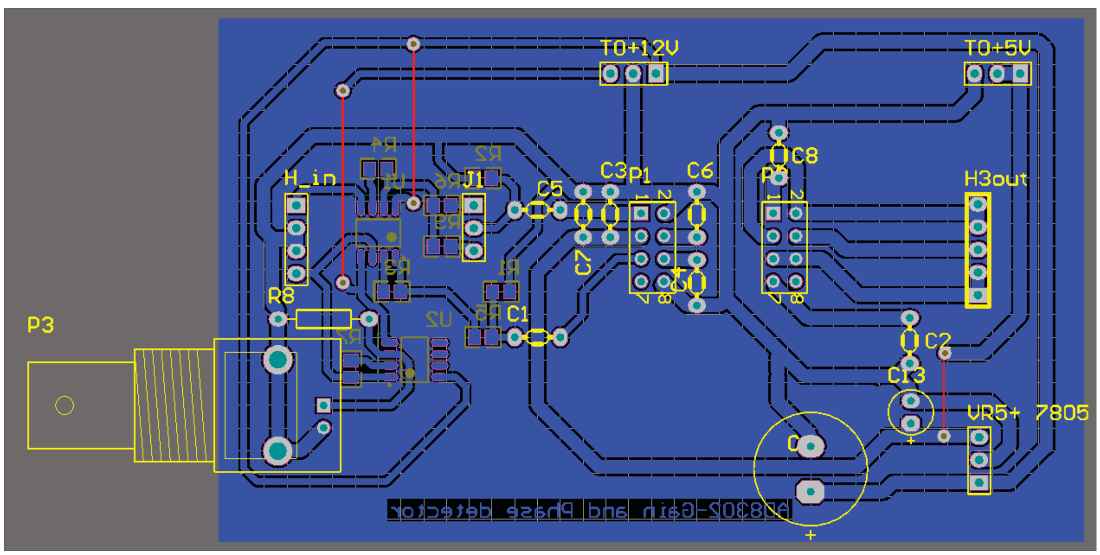


Figure 43: The Designed PCB for the Connection Circuitry Between Systems

(Figure 44) shows the voltage regulators for powering the AD8302, where the higher 12V power supply is required for the rest of the system.

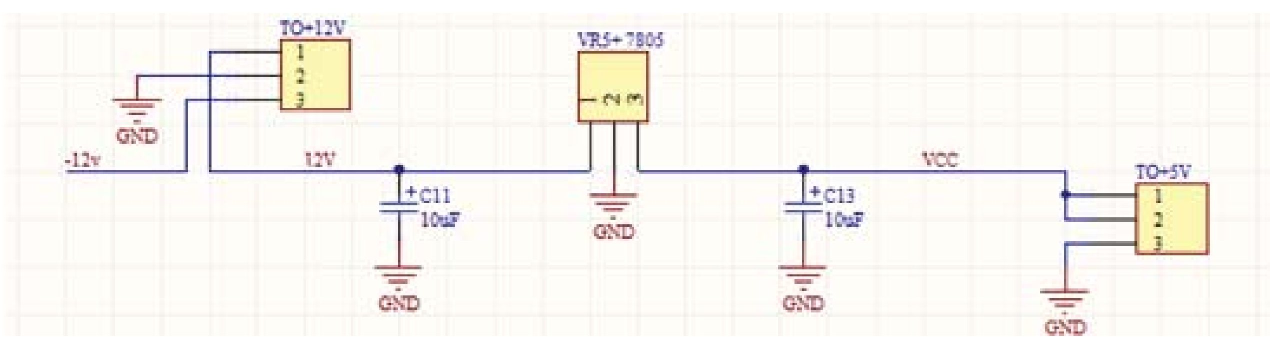


Figure 44: +12V Voltage Supply goes through 5V Regulator for AD8302

The input buffers were implemented using high speed, low output impedance amplifiers THS3061 [39], as shown in (Figure 45). Input buffers consist of a unity gain buffer and a voltage attenuator with a 680 Ω resistor and a 50 Ω resistor. The attenuator was implemented in order to try and match the input impedance of the AD8302 as well as to reduce signal amplitude into the range between 316 μVpeak and 316 mVpeak for AD8302[40].

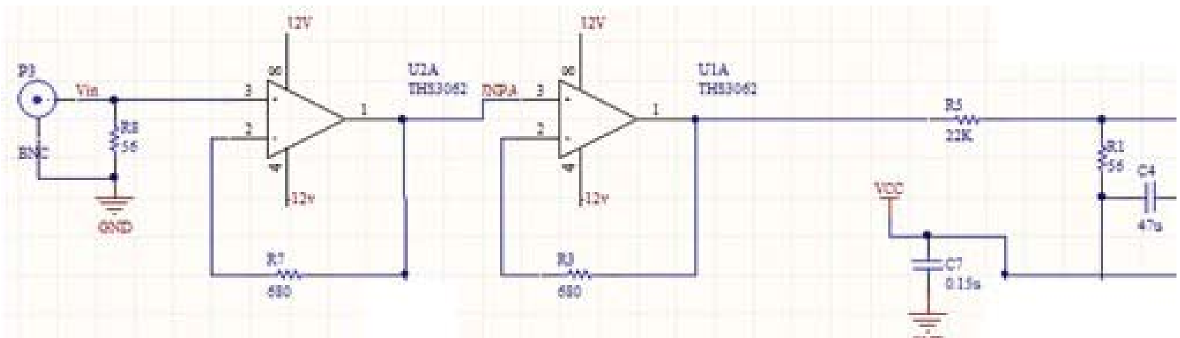


Figure 45: Signal Generator Output into Buffer Attenuator

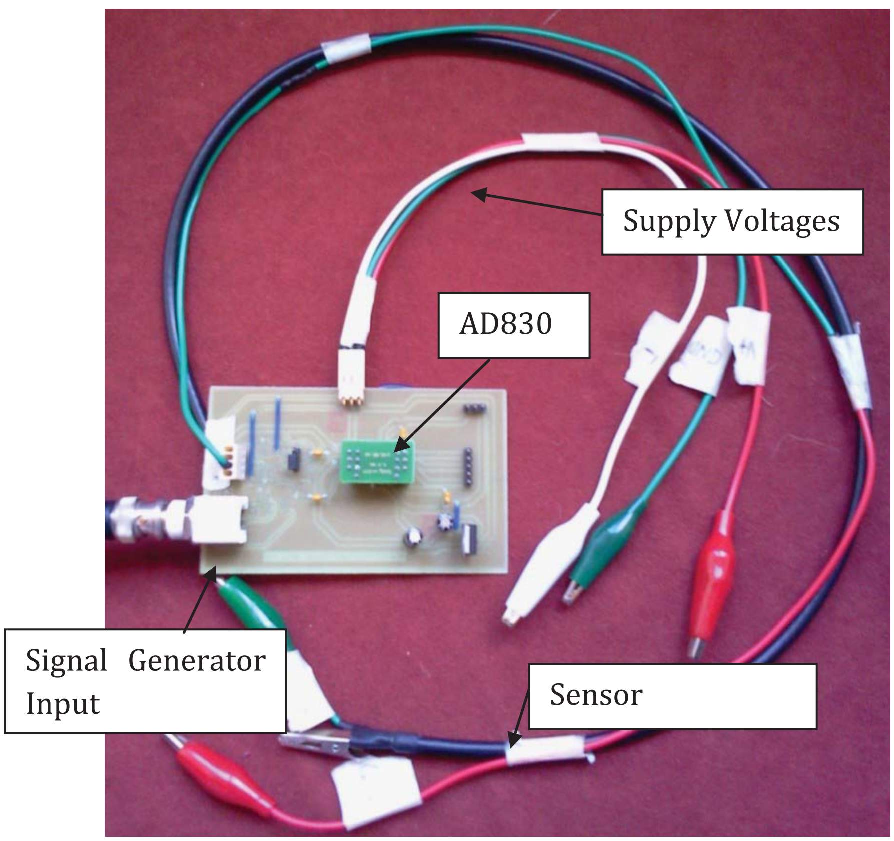


Figure 46: Image of Gain and Phase Detection Circuit

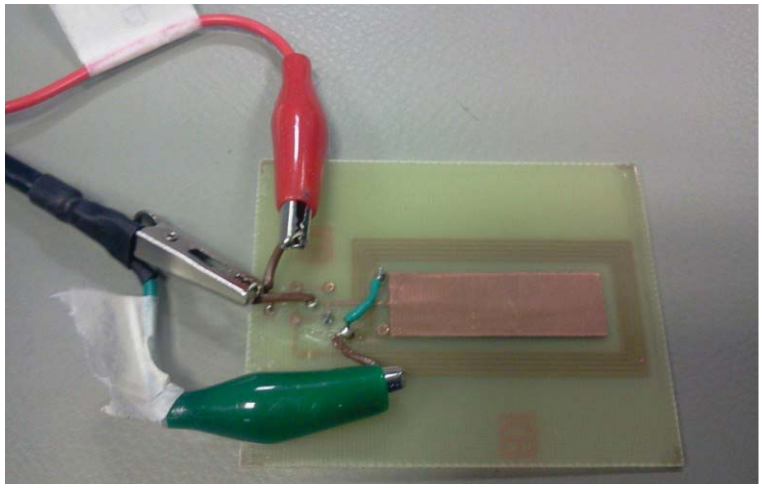


Figure 47: Sensor Connection

Unfortunately, when connected there appeared to be distortion of input waveforms, which meant that the resulting outputs (Figure 48) showed results for AD8302 outputs as being quite noisy, although this may be improved with additional filtering. It appears that a significant amount of precision and accuracy has been lost for measurements. Further investigation is still required before integration of the nitrate detection system to the Wi-Fi based WSN.

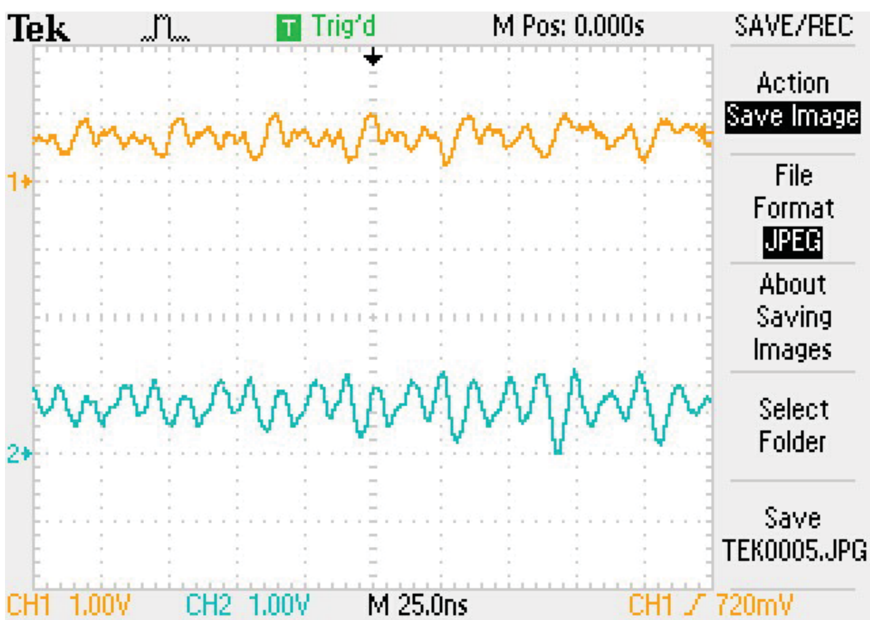


Figure 48: Output Circuit Values

4) WIRELESS TECHNOLOGIES

4.1. EXISTING WIRELESS TECHNOLOGIES

One of the main advantages of WSN's is reducing cable network complexity and operational cost in the desired applications. There have been many wireless technologies developed over the last few decades to deal with these issues. Thanks to the increasing trend in the wireless communication industry, many modern day applications are capable of providing a good level of flexibility, mobility at low cost and low power consumption.

Although there are a large number of wireless technologies which include Radio Frequency Identification (RFID), Near Field Communication (NFC), Infrared (IrDA) and Cellular Network (CDMA/GSM) a survey was conducted in order to determine the popularity of various wireless technology and it was discovered that the most exploited wireless technologies in modern day industries are: Wi-Fi, Bluetooth and ZigBee [41]. Each wireless technology has its own advantages and disadvantages; therefore, a careful selection of a suitable wireless technology for the intended application is essential.

A comparison of the following four wireless standards authored by the Institute of Electrical and Electronics Engineers (IEEE) [42] was done. The IEEE 802 Wireless Systems are seen as some of the leading systems [43] and include the following technologies of interest:

- Bluetooth Wireless Technology (IEEE 802.15.1)
- Wi-Fi (IEEE 802.11)
- WiMAX (Worldwide Interoperability for Microwave Access and IEEE 802.16)
- ZigBee (IEEE 802.15.4)

4.2. 802.15.1 BLUETOOTH

The IEEE 802.15.1 standard [44] is the basis for the Bluetooth wireless communication technology. Bluetooth is an ad hoc, terrestrial, wireless standard. Bluetooth wireless technology is a short range wireless communication intended to replace the cables connecting portable or fixed devices while at the same time maintaining a high level of security. The technology operates with three different classes of devices: Class 1, class 2 and class 3 where the range is about 100 meters, 10 meters and 1 meter respectively. Wireless LAN operates in the same 2.4 GHz frequency band as Bluetooth to communicate but the two technologies use different signalling methods. Bluetooth employs the frequency hopping spread spectrum, (FHSS) modulation technique [41], which helps minimise interference.

A few key features:

- Bluetooth technology operates in the unlicensed industrial, scientific and medical (ISM) band at 2.4 GHz, using a spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/sec
- Data Rate of 1 Mbps for Bluetooth low energy technology [41] [45]
- Range may vary depending on class of radio used in an implementation
- Depending on the Radio class Bluetooth provide 1-100 meters [41]
- P2P Network

4.3. 802.11 WI-FI

Wi-Fi, also known as Wireless LAN (WLAN) The WLAN standards operates on the 2.4 GHz and 5 GHz Industrial, Science and Medical (ISM) frequency bands and has a distance of 100m [46][41][45]. It is specified by the IEEE 802.11 standard [47] and it comes in four major different variations like IEEE 802.11a/b/g/n. Each generation is defined by a set of features that relate to performance, frequency and bandwidth. The application of WLAN has been most visible in the consumer market where most portable computers support at least one of the variations.

Although Wi-Fi was intended to be used for mobile computing devices such as laptops, in LANs, it is now used for increasingly more applications, including Internet, gaming, and basic connectivity of consumer electronics such as mobile phones, televisions and DVD players.

A few key features:

- Interoperability – means any Wi-Fi product from different manufacturers can work together
- Backward compatibles – means new Wi-Fi products are able to work with older Wi-Fi products that operate in the same frequency band
- Robustness
- Flexibility
- IP & P2P based Networks
- Distance of 100m
- Choice of modes
    - Ad-Hoc mode allows stations to form a wireless LAN, in which stations communicate with each other in a peer-to-peer manner
    - Infrastructure – the network has an access point, through which all other stations communicate

4.4. 802.16 WIMAX

The IEEE approved the 802.16 standards [48]. WiMAX allows for higher data rates with speeds of 75Mbps, over longer distances of about 48 km depending on the base stations. It has a frequency range of 2-11GHz where WiMAX allows for wireless networking similar to Wi-Fi [45] while avoiding interference. WiMAX is meant to enable rapid deployment of innovative, cost-effective, and interoperable multivendor broadband wireless access products [48]. It looks at providing alternatives to wireline broadband access.

The bandwidth and range of WiMAX make it suitable for the following applications:

- Providing portable mobile broadband connectivity across cities and countries through a variety of devices.
- Providing a wireless alternative to cable and broadband access.
- Providing time dependent data such as VoIP

Features of WiMAX include:

- Security via station authentication and encryption
- IP Based Networks
- Distance of 48km

4.5. 802.15.4 - ZIGBEE

ZigBee is a low tier, ad hoc, terrestrial, wireless standard in some ways similar to Bluetooth. The IEEE 802.15.4 standard [49] is commonly known as ZigBee, but ZigBee has some features in addition to those of 802.15.4. It operates in 2.4 GHz ISM bands. Zigbee is a low-rate Wireless personal area network which can convey information over a relatively short distance [49] of 70 m and relatively simple devices [41]. It uses DSSS, direct sequence spread spectrum [41]. It has a Mesh Master / Slave topology. The ZigBee technology uses hybrid star networks, which uses multiple master nodes with routing capabilities to connect slave nodes [45].

A few key features: [45]

- Industrial, scientific and medical (ISM) band at 2.4 GHz,
- Data rate of 250kbps at
- DSSS,
- Power Management Features
- Simple Networking Configuration
- Mesh Master / Slave topology
- Distance of 70m

4.6. COMPARISON BETWEEN THE TECHNOLOGIES

The various technologies of WiMAX, Wi-Fi, Bluetooth, and ZigBee can be classed into different area networks [45] WiMAX can be classified as Metropolitan area network due to its large range, Wi-Fi as a Local area network due to is average range and Zigbee and Bluetooth as Personal area network due to its short range.

While there are many wireless technologies available on the market, ZigBee, Bluetooth and Wi-Fi are the major technologies that are readily available to deliver the performance and low cost desired. Although WiMAX is a technology of interest especially with the distance attainable, the power consumption makes its feasibility questionable. Each wireless technology has its strengths and weaknesses and having a good understanding of these characteristics will allow the end users to determine the most suitable wireless technology for their applications. (Table 6) shows the comparison of these three wireless technologies, wireless LAN, Bluetooth and ZigBee. It displays information based on the basis of their frequency range, technology, performance, range, power consumption etc.

Table 6: Comparison between Wireless LAN, Bluetooth and ZigBee [41]

Feature	WiFi (IEEE 802.11b)	Bluetooth (IEEE 802.15.1)	ZigBee (IEEE 802.15.4)
Radio	DSSS[a]	FHSS[b]	DSSS
Data rate	11 Mbps	1 Mbps	250 kbps
Nodes per master	32	7	64,000
Slave enumeration latency	Up to 3 s	Up to 10 s	30 ms
Data type	Video, audio, graphics, pictures, files	Audio, graphics, pictures, files	Small data packet
Range (m)	100	10	70
Extendability	Roaming possible	No	Yes
Battery life	Hours	1 week	>1 year
Bill of material (US$)	9	6	3
Complexity	Complex	Very complex	Simple

[a] DSSS, direct sequence spread spectrum.
[b] FHSS, frequency hopping spread spectrum.

Wi-Fi technology is a network technology developed for data-intensive communication such as video audio and other media. Bluetooth is considered as primarily a short distance cable replacement for point-to-point consumer devices with little ability of extendibility and the ZigBee typically has very low bandwidth (250 kbps). Wi-Fi provides the highest bandwidth of wireless technologies. In particular The Wi-Fi WSN802G module, for example, provides up to 11 Mbps, with a fallback to 1 Mbps. ZigBee offers less than 250 kbps, or less with little fallback.

Additionally when it comes to data protection, Wi-Fi provides highly tested link layer encryption, authentication (WPA2, EAP, TLS/SSL) and end-to-end network security. It is also easy provisioning & IT friendly, where as Zigbee testing has been limited in comparison, security holes identified [50] and is less familiar to IT.

Based on the information provided by (Figure 49), Wi-Fi and Bluetooth, appear to have much higher power requirements, therefore battery running time will be a lot shorter - with ZigBee technology capable of providing low power networks and devices that could run for years on inexpensive batteries. However, it is important to note (Figure 49) doesn't take into account recent improvements in particular with speciality WSN802G Wi-Fi technology that address power requirements and has allowed for 5 year battery life [51] — these modules have ability to sleep between active periods.

The protocol complexity between each device was compared and the result shows that Bluetooth is the most complicated protocol. ZigBee on the other hand is the simplest one, followed by Wi-Fi [41][46].

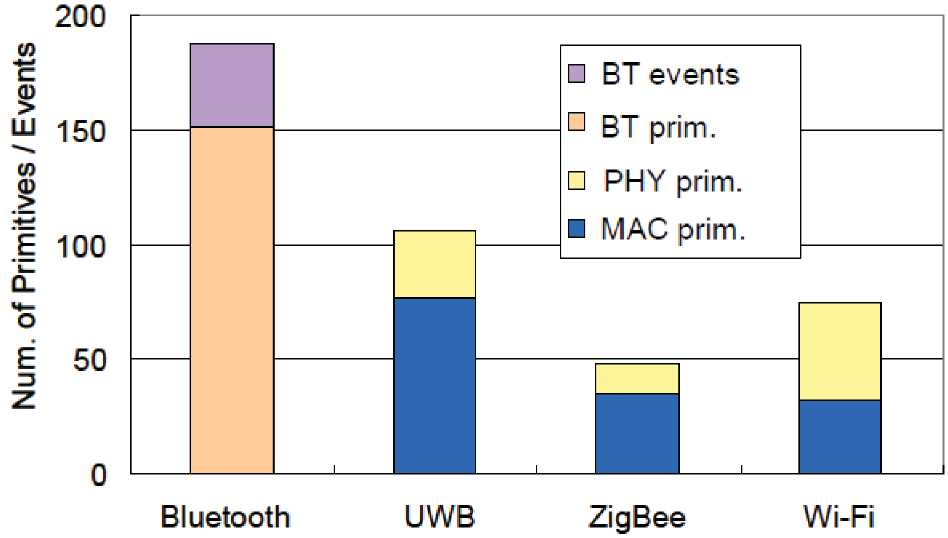


Figure 49: Comparison of the Complexity for each Protocol [46]

Although there are advantages to having a lower protocol complexity, ZigBee has some technical shortcomings, such as address allocation, scalability, management tools, routing mechanisms, and interoperability with the Internet [7]. Even though Zigbee is an advertised wireless sensor network standard that has been around a while now, its adoption has been limited in comparison to Wi-Fi.

In addition several variants and versions have emerged where very little multi-vendor activity has occurred. As a result Zigbee vendors seem to be offering closed loop systems where interoperability between products from different manufacturers is nowhere near on the same scale that Wi-Fi is.

Since ZigBee is still an inexperienced protocol, currently available management software is thus a little immature, especially when it is necessary to manage a large scale network. Wi-Fi on the other hand is past adoption cycle. The recent advances in the integration level of the chips, and specific targeting of low power applications by chip vendors [52] make Wi-Fi more desirable for applications in environments where managed Wi-Fi has become a necessity.

Wi-Fi with IP-based network management tool has been developed for decades. It is rather easy to find mature protocols to support network management in an IP network. For example, SNMP [53] (Simple Network Management Protocol) is an IP-based network management standard which can collect, modify and exchange network management information between network devices and is implemented in WSN802G Wi-Fi Modules.

If a wireless sensor network is developed based on the IP protocol, it does not need any additional application-layer translation which is mandatory for ZigBee networks. There have been suggestions made that future deployment of wireless sensor network devices should be IP-based, so that they can be easily managed remotely [54]. None of other wireless technology is as IP friendly as Wi-Fi. Wi-Fi allows for easy connection to Web enabled services. Even for IP based ZigBeeIP this is not true [54][50] as it requires the use of a bridge. Additionally since Wi-Fi works with existing access points, it lowers cost even though ZigBee might have lower node costs. ZigBee would require new infrastructure that means additional costs along the line.

5) WSN802G WI-FI MODULE

5.1. WSN802G INTRODUCTION

The WSN802G transceiver module is a low cost, robust solution for 802.11b/g/n sensor networks. A unique feature of the WSN802G module is that it is able to sleep between active periods while still remaining a member of an 802.11b/g/n network. It has a sleep current of <8 uA, and active power current of <200 mA. The WSN802G's low active current compared to 802.11b/g cards used in notebook and handheld computers, and very low sleep current makes long life battery operation practical and has enabled up to 5 year battery life[51]. The WSN802G is stated as having a RF power of 10mW where having a RF power value of 10mW and less aims at a longer battery life [51].

In addition to the addressed consumption issue often associated with Wi-Fi the WSN802G module features still provide the following features and specifications [52]:

- Compatibility with commercial and industrial 802.11b/g routers
- Low power consumption for long life battery operation including sleep mode
- Full -40 to +85 ºC industrial temperature range operation
- Analog and digital I/O plus data and diagnostic UART ports
- Separate data and diagnostic ports
- Full 14 channel 802.11b/g coverage for world wide operation
- FCC, Canadian IC and European ETSI certifications
- Automatic (without polling) or manual (polling) I/O data reporting
- Small Dimensions (Figure 50)

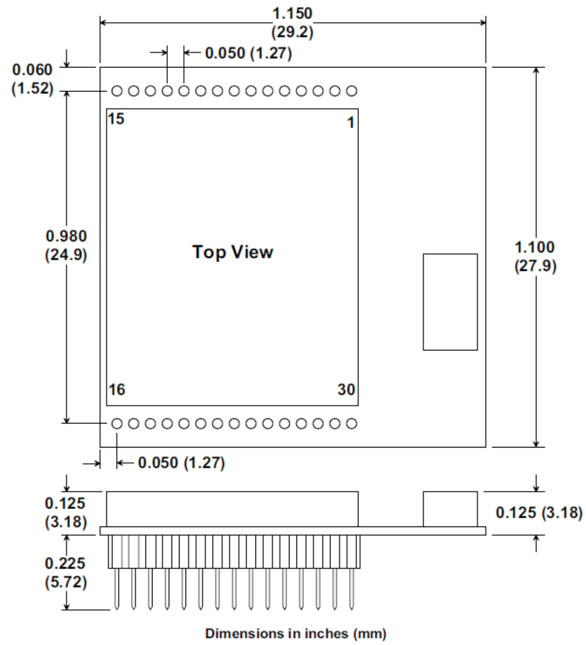


Figure 50: WSN802G Module Dimensions

The WSN802G module includes analog, digital and serial I/O, providing the flexibility and versatility to serve a wide range of sensor network applications. WSN802G sensor networks are well suited to applications where it is important to have IEEE 802.11b/g router compatibility, long battery life and industrial temperature range operation. Many applications match these criteria, including [52]:

- Environmental monitoring
- Depot and machinery zones
- Seaports, Off-shore platforms
- Airports
- Energy monitoring and management
- Oil and gas wells and areas
- Tank farms (level measurements, valve controls)
- Agricultural measurements and controls
- Factories, warehouses
- Cold chain data logging and food safety, temperature controlling

- Move sensors, street light control
- Security, Access control and customer counting applications
- Roof conditions monitoring, snow coverage control

The WSN802G module compatibility with standard 802.11b/g/n routers helps utilise existing Wi-Fi 802.11b/g infrastructure, meaning that this helps reduce cost since no additional base stations or gateways are needed. A sensor network application running on a server or PC can communicate with one or more WSN802G sensor nodes through a commercial 802.11b/g/n router (Figure 51) where WSN802G sensor nodes can be used with 802.11b/g/n routers that are also serving other applications [52]. In addition the WSN802G modules FHSS Wireless Telemetry allows for Point-to-Point and Point-to-Multipoint Networks.

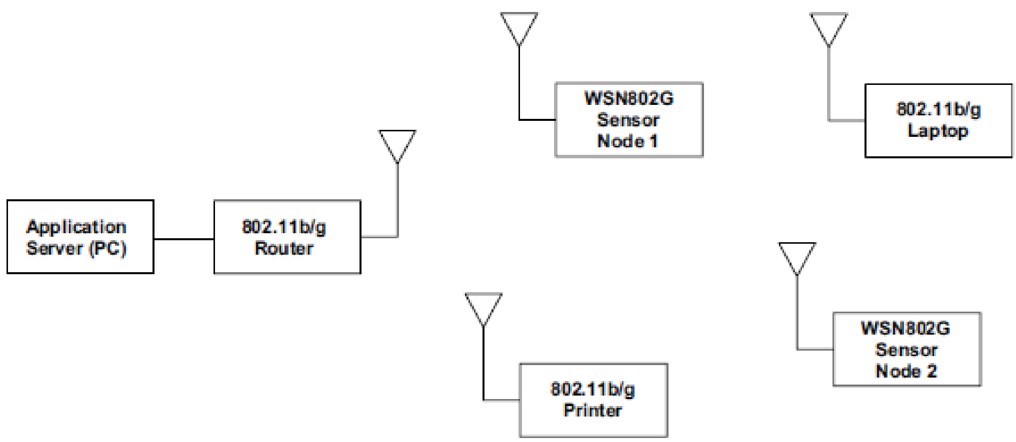


Figure 51: A Sensor Network Application Communicates with one or more WSN802G Sensor Nodes through a 802.11 Router that can also be Serving other Applications [52]

The WSN802G features configurable automatic I/O reporting and the ability to collect sensor data directly from devices using its ADCs, GPIOs and Serial I/O. The WSN802G is also user programmable. There is no need to write applications to load into the module for implementation. The sensor network application on the server or PC (Figure 51) uses a simple protocol to send and receive data from WSN802G sensor nodes where WSN802G modules can receive configuration commands through either their serial port or over-the-air in UDP packets carrying SNMP commands [52].

5.2. WSN802G RATINGS

The WSN802G radio modules can operate from an unregulated DC input (Pin 14) in the range of 3.0 V to 3.63 V over a temperature range of -40 to 85°C. Any voltage outside the specified range given can cause damage. Care must be taken so logic inputs applied to the module stay within the voltage range of -0.5 to 3.63 V (Table 7). Signals applied to the analogue inputs must be in the range of 0 to 1.98V. Applying a voltage to a logic or analogue input outside of its operating range can damage the WSN802G module.

Table 7: Maximum Rating WSN802G Modules [52]

Rating	Sym	Value	Units
Input/Output Pins Except ADC Inputs		-0.5 to +3.63	V
ADC Input Pins		-0.5 to 1.98	V
Non-Operating Ambient Temperature Range		-40 to +85	°C

5.3. WSN802G CONFIGURATION

5.3.1. Introduction

The WSN802G wireless module comes preconfigured for use with certain wireless router settings where the default channel is 11 with an SSID of "WSN-Default" in secure mode. The security passphrase to allow router access is "WSN-PASSWORD". However to configure WSN802G module, and make changes in configuration a software program called WSNConfig is required. This software was provided by RFM along with its source code so as to allow for editing to better suit applications needs. (Figure 52) shows the layout of the WSN8Config program.

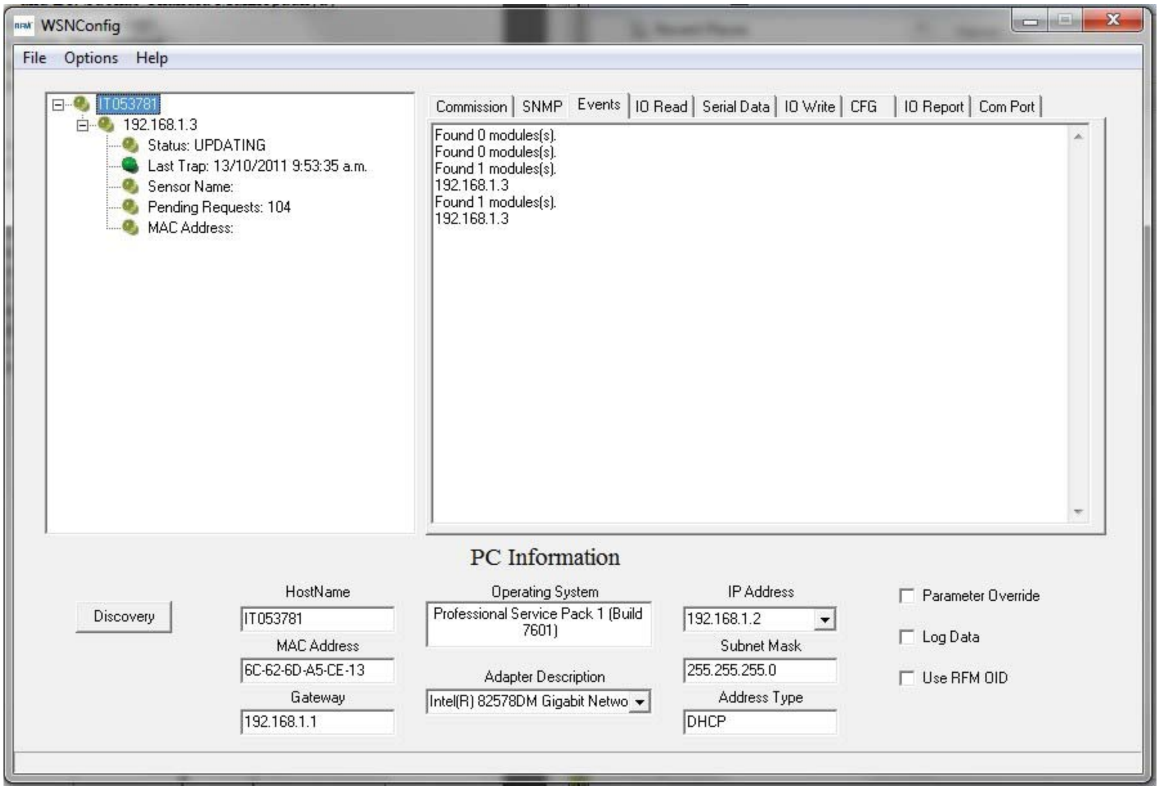


Figure 52: WSNConfig Application used for Initial Discovery of Sensor Node and Retrieving Information

The software program consists of 9 main tabs: Commission, SNMP, Events, IO Read, Serial Data, IO Write, CFG Tab, IO Report and Com Port:

- Commission tab – Allows the selection, the action and configuration of the WSN802G module such as Sensor Server IP Address
- SNMP Tab – Allows individual MIB parameters to be manually displayed and modified
- Events Tab – a running history of events received from the WSN802G module
- IO Read Tab – Allows the sending of IO_REPORT_REQUEST to the module. Which is returned with readings for IO values
- Serial Data Tab – Allows a desired string to be transmitted from a text box in a SERIAL_DATA command to the module
- IO Write Tab – Allows IO_WRITE_GPIO and IO_WRITE_PWM commands to the module to change values

- CFG Tab – Allows the API CFG commands to be routed in UDP packets over the wireless link
- IO Report Tab – Allows charting from of the IO Report parameters within the Configuration program
- Com Port Tab – Allows access to the same parameters through the serial port that can be accessed by the SNMP server

5.3.2. Module Discovery

The WSN802G module supports a separate UDP client port that provides a discovery protocol for wireless communications. This discovery protocol is used to find IP addresses of modules in a network when the IP addresses have been assigned by a DHCP server [52]. Since the IP addresses of potential recipients might not be known, both query and reply messages are sent as UDP broadcasts. Once the WSNConfig.exe program is executed clicking on the Discovery button, will display the IP addresses of the WSN802G module near the top left hand text box on the WSNConfig window (Figure 52). The discovery protocol is also used to set the module's SNMP Server IP addresses which enables module commissioning. This protocol uses port 24776 [52].

If the server is on multiple networks you can select the desired network interface as well as the IP address for use within the WSNConfig application (Figure 53). This allows for easier configuration of modules for more complex network situations with multiple networks and interfaces without disconnecting.

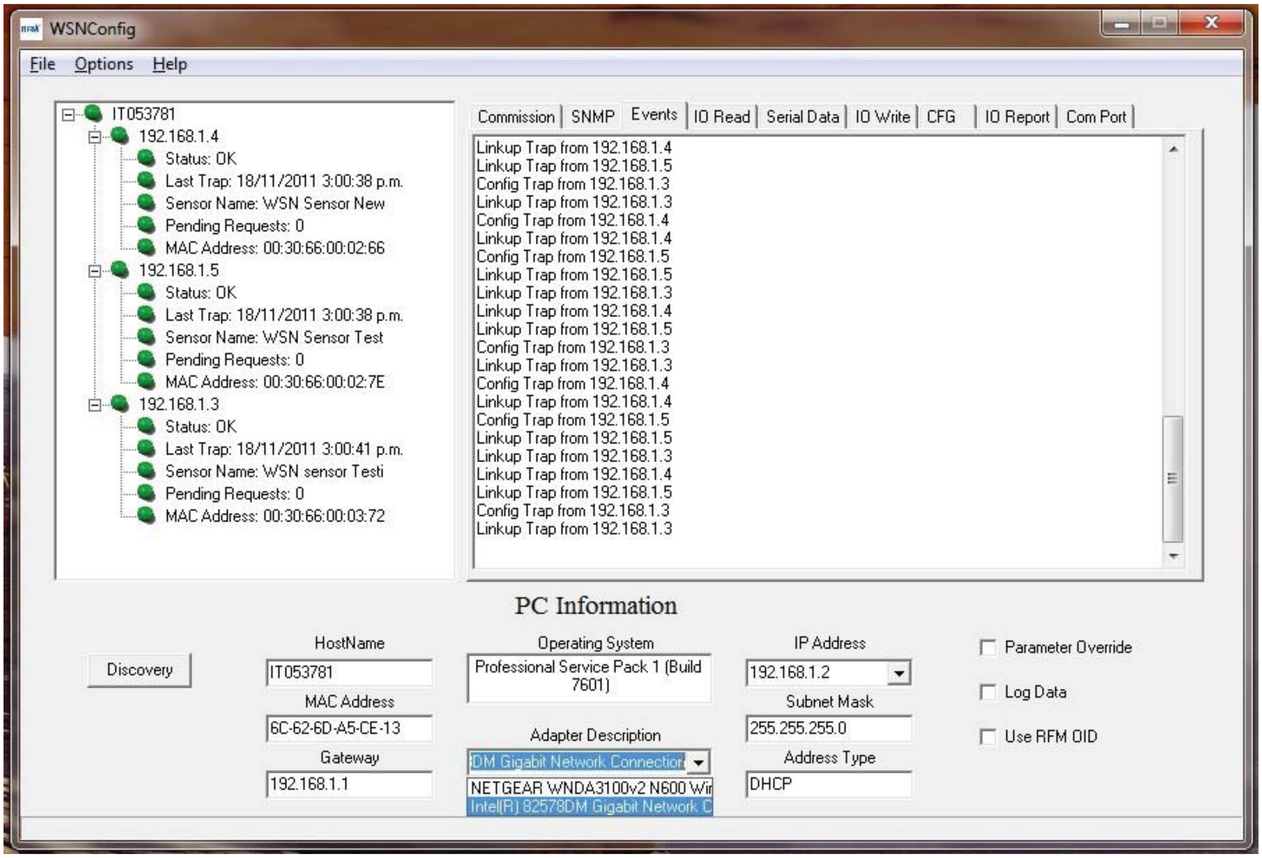


Figure 53: Server on Multiple Networks allows Easy Selection

5.3.3. Module Commissioning

An un-commissioned module stays in active mode until its primary SNMP server address has been set. A WSN802G module can be configured by SNMP maintenance commands sent over the wireless link in response to the module's SNMP configuration requests (Config. traps) [52] in order to commission the module Select Sensor Server IP address from the Select Item drop-down box on the WSNConfig.exe Commission tab (Figure 54).

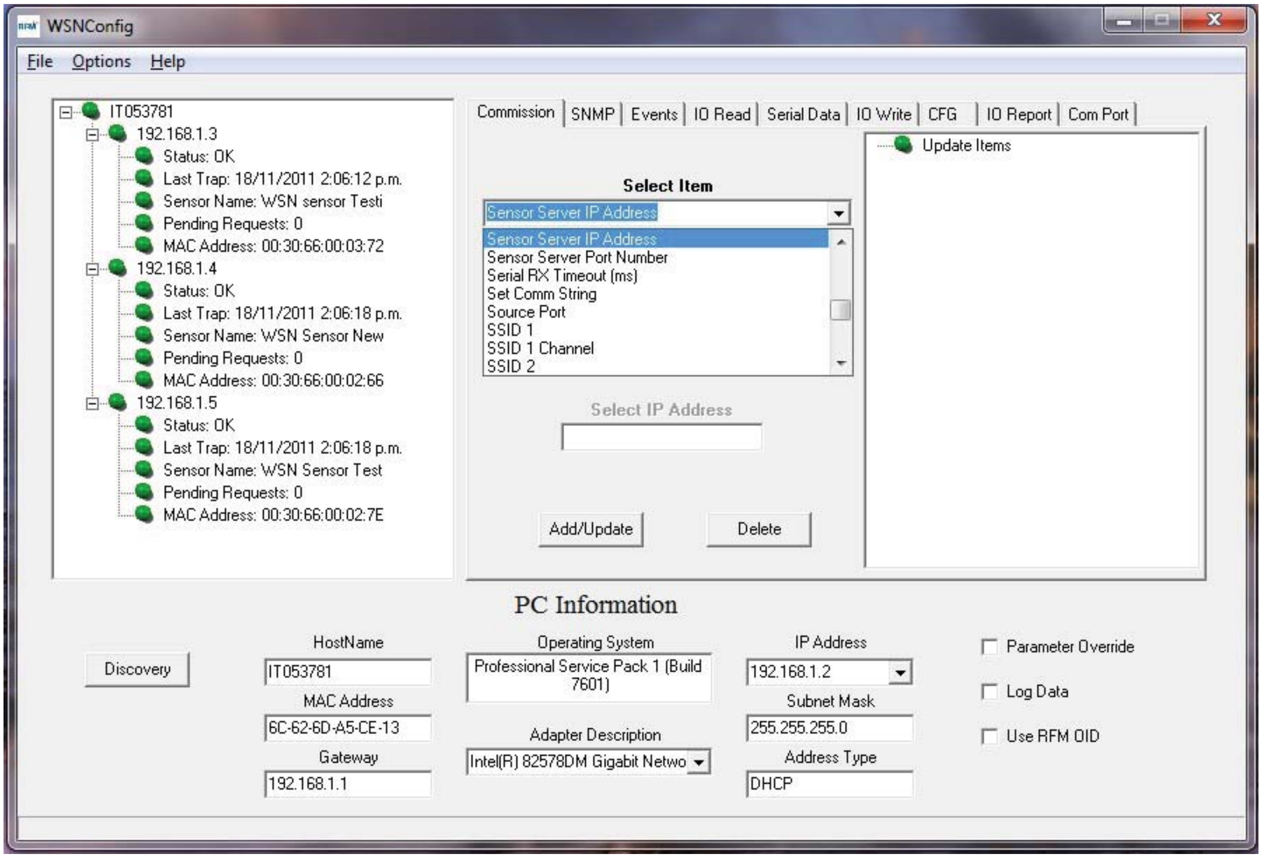


Figure 54: Select Item Sensor Server IP Address

The IP Address of the desired server computer can be acquired from the "PC Information" area or by other means and entered in the "Item Value" text box. Clicking the Add/Update button (Figure 55) configures the WSN802G modules to send its periodic I/O_READ data to the PC running WSNConfig.exe.

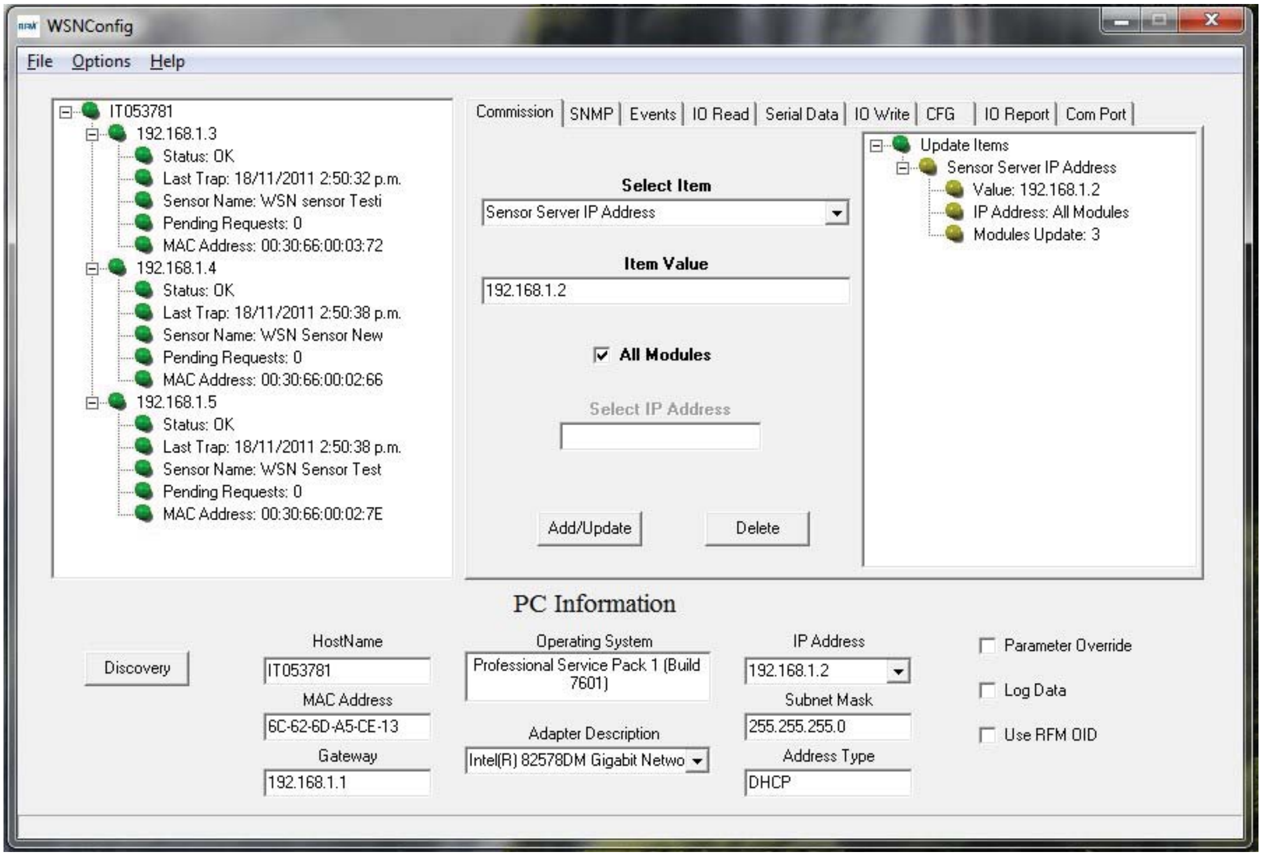


Figure 55: All Modules Commissioned with Same Sensor Server IP Address

The WSNConfig utility allows for each node to be configured independently (Figure 56) or all modules as a whole (Figure 55). Individual settings may be configured or a list of configuration parameters can be queued for transmission when the node or nodes wake up and issue the Config Trap. Alternatively, a third party SNMP server or utility may be used to serve the same function [52].

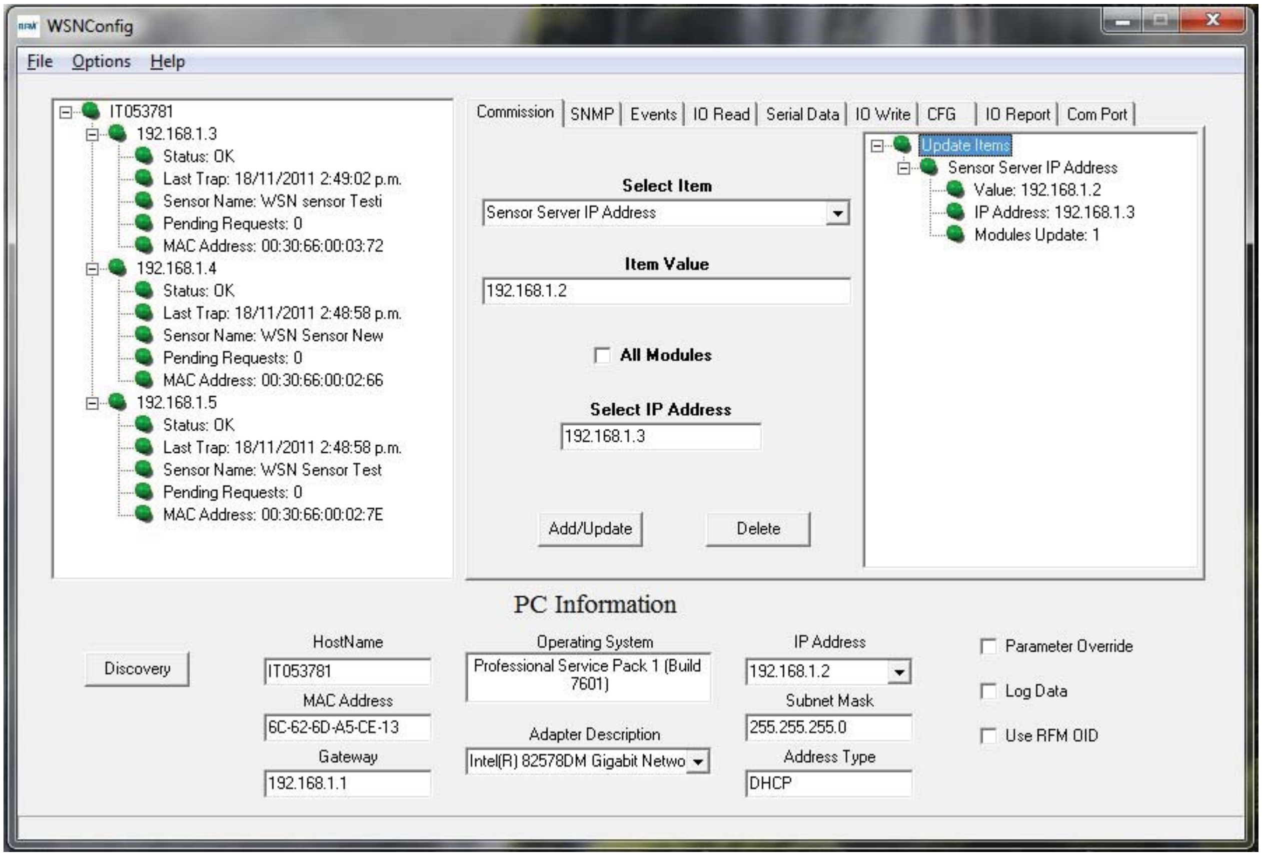


Figure 56: Commissioning a Single Selected Module with the Specific Sensor Server IP Address

The Server IP address can be set in a short period of time, allowing the module to switch to sleep mode for battery conservation. The SNMP Server IP Address needs to be configured just once. This parameter holds the IP address of the server for the module to send sensor data reports. The IP address is formatted as a 32-bit value.

If everything is setup correctly, wireless communication has been established between coordinator and end devices. This type of communication is referred to as a point to multi-point communication. In addition there are features in place to allow for Ad-hoc or point to point communication.

5.3.4. Module Configuring

Double clicking on a module IP address in the left text box of the main WSNConfig frame launches a multi-tab configuration dialog box for the module, as shown in (Figure

57). The Config dialog frame has Refresh, Get All, Apply, Default and Reboot buttons. The WSNConfig.exe maintains a local buffer that holds a copy of configuration parameters.

- The "Refresh" button loads the configuration parameters from the local buffer into various tabs in the Config dialog box.
- The "Get All" button queues a request to the WSN802G module to send a new copy of all its configuration parameters.
- The "Apply" button followed by clicking on the "Reboot" button will queue a request to the WSN802G module to modify parameter values that have been changed in a Config tab.
- The "Default" button followed by clicking on the "Reboot" button queues a request to the WSN802G module to load factory default values for all configuration parameters.

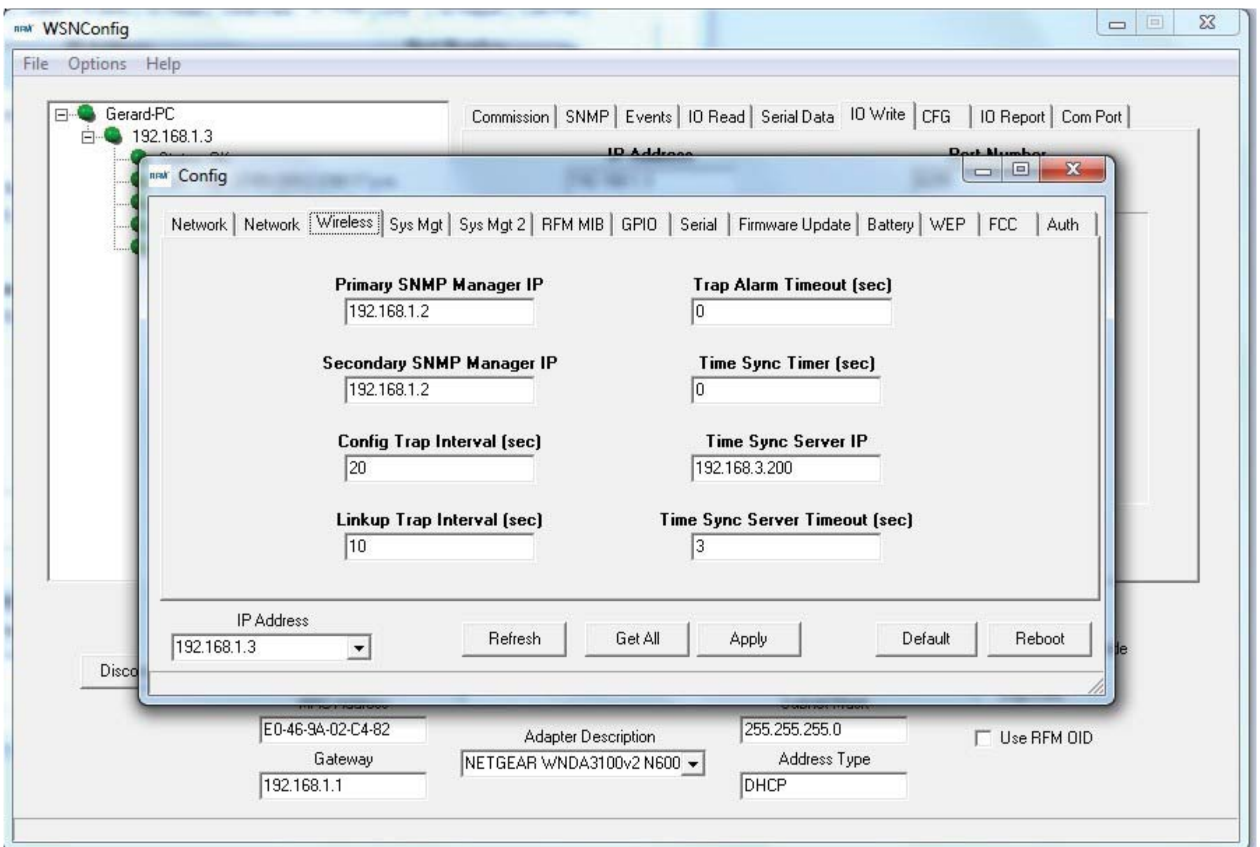


Figure 57: Configuration Dialog Box for the Module where Trap Interval can be Set

Config Traps

A Config trap is a message sent periodically to poll the SNMP server to see if it has any commands waiting. These Config traps are transmitted to server IP address [52]. Upon sending the trap, the module remains awake for a period of four seconds to allow the server to send it commands. A default value of 20 seconds is set for the module Config interval trap. The interval between Config traps is configurable by double clicking on a module IP address and adjusting Config trap interval parameter in Config dialog frame (Figure 57). It is recommended that for battery-powered deployments the config trap interval should be set to once an hour or a few times per day to conserve battery life [52]. The less frequently Config Traps are issued by the module, the longer the battery life will be, but it takes longer to change the module's configuration over the wireless link. Upon receiving a Config trap, the server sends a Config Complete command to indicate it has finished sending or has no commands to send. This allows the module to return to sleep mode, rather than remaining in active mode for the rest of the configuration window.

Linkup Traps

The Linkup trap is a message sent periodically by the module to maintain its association with its 802.11b/g/n access point. No useful information is conveyed, except to notify it's presence within the network. For compatibility with the majority of 802.11b/g/n Access Points/Routers, the default period is 10 seconds. However, depending on Access Point/Router the period of the Linkup trap can be adjusted to suit and is set by the Linkup Trap Interval system parameter (Figure 57). Note that the Specification states that this parameter should not be set above two minutes [52].

I/O Reports

The I/O Report transmits current I/O values. The I/O Report datagram [52] demonstrates the various items of interest (Figure 58). The I/O Report contains values for source MAC address, ADC values, module voltage supply, Received Signal Strength Indicator

(RSSI) and the GPIO states defined as inputs. The information is generated depending on the defined time between reports, called the Auto Report Interval in the RFM MIB Tab in the Config dialog frame (Figure 57) and in response to a user initiated IO_READ_REQUEST. The default Auto Report Interval is set at 10 seconds to coincide with Linkup traps in order that module awake occurrences are at a minimum.

Byte 0	Byte 1	Byte 2	Byte 3
WSN802G Protocol Identifier = 0x52464D49			
Opcode = 0x0001		Transaction ID = varies	
Timestamp [7..4]			
Timestamp [3..0]			
MAC Address Bytes [5..2]			
MAC Address Bytes [1..0] (sender)		ADC0	
ADC1		VOLT	
RSSI		GPIO	

Figure 58: Datagram of I/O Report used for Reporting of I/O Values [52]

The WSN802G sends an I/O report when one of the following events occurs:

- A logic high signal is applied to the WAKE_IN pin
- The AutoReport timer fires (module in either active or sleep mode)

5.4. WSN802G COMMUNICATION TESTING

5.4.1. Introduction

Tests were carried out upon the WSN802G modules. Upon correct configuration and connection with the WSNConfig application, it is possible to see the various Config traps, Linkup traps and IO Read Packets sent from the different IP addresses in the Events Tab - a running history of received transmissions from the WSN802G modules (Figure 59). However the events tab is very limited in regards to specific details such as times transmissions occurred.

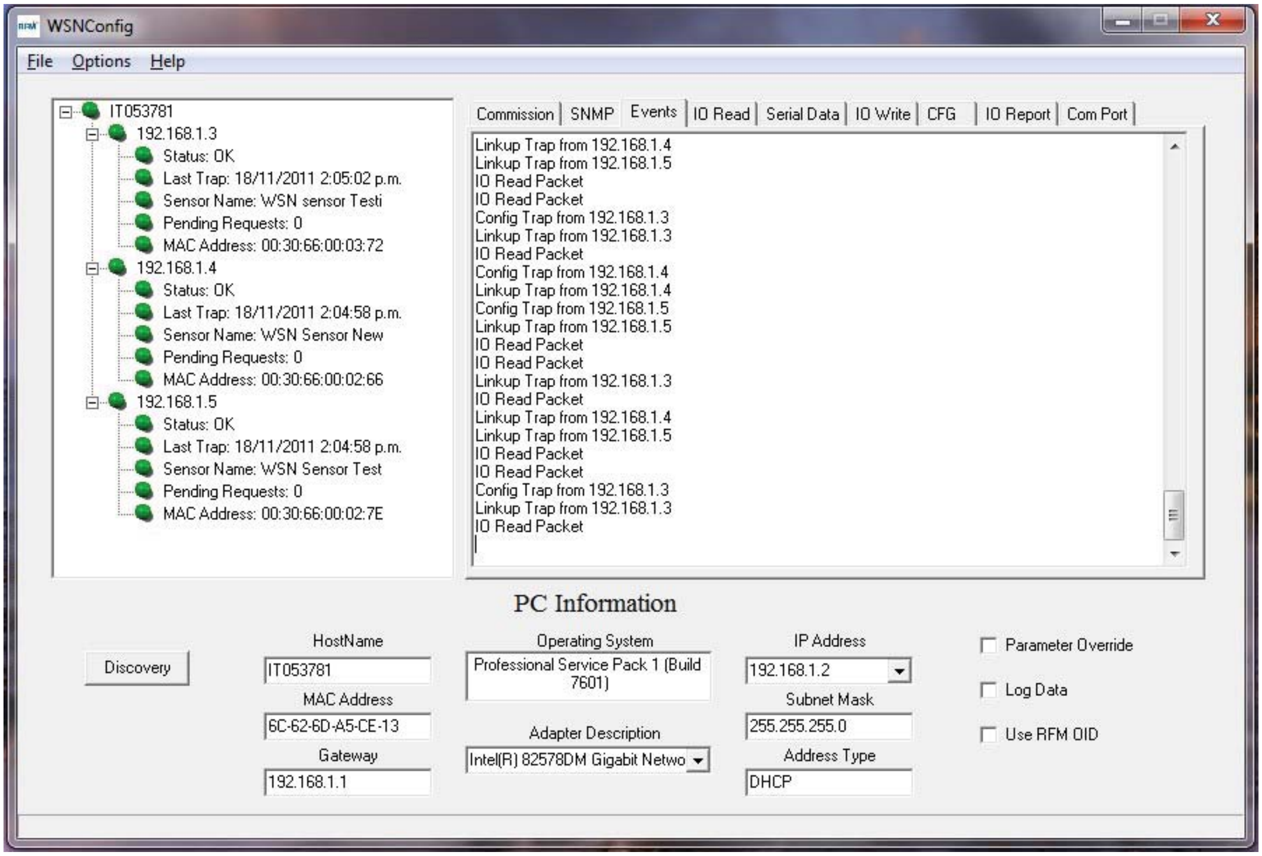
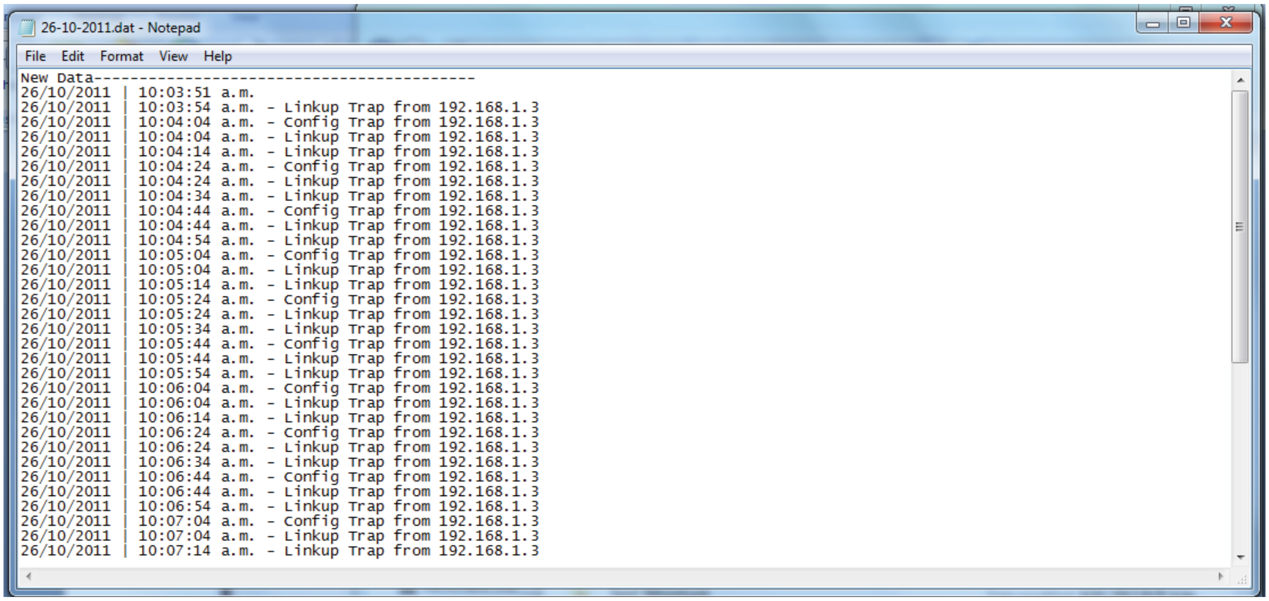


Figure 59: Events such as Linkup, Config and IO Report can be Seen Once Server IP Address is Set and Connected

5.4.2. WSN802G Logs

The WSNConfig program allows logging of events such as trap times and IP addresses of originating traps. The data that is logged includes Config and Linkup traps (Figure 60). This allows for good trouble shooting of modules during the initial stage of configuration as it is possible to observe the module's behaviour in comparison to expected behaviour based on the configuration parameters set.


26-10-2011.dat - Notepad

File Edit Format View Help

```
New Data----------------------------------------
26/10/2011 | 10:03:51 a.m.
26/10/2011 | 10:03:54 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:04:04 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:04:04 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:04:14 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:04:24 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:04:24 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:04:34 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:04:44 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:04:44 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:04:54 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:05:04 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:05:04 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:05:14 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:05:24 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:05:24 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:05:34 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:05:44 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:05:44 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:05:54 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:06:04 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:06:04 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:06:14 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:06:24 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:06:24 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:06:34 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:06:44 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:06:44 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:06:54 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:07:04 a.m. - Config Trap from 192.168.1.3
26/10/2011 | 10:07:04 a.m. - Linkup Trap from 192.168.1.3
26/10/2011 | 10:07:14 a.m. - Linkup Trap from 192.168.1.3
```

Figure 60: The WSNConfig Program Allows Logging of Occurring Trap Times and IP Address of Originating Trap.

(Figure 60) shows the Config and Linkup traps occur at intervals of 20 and 10 Seconds respectively. The module's behaviour matches up to the expected behaviour with configuration parameters set for Config Trap Interval 20 Seconds and Linkup Trap Interval of 10 Seconds. There were no missing or out of order traps occurring while testing. Although this information is useful it shows only a small part of what occurs within the network.

5.4.3. Wireshark Testing

The system's commands and responses sent through the network are formatted as UDP/IP packets [52]. WSN802G application protocol datagrams use a standard header beginning with a protocol identifier to discriminate WSN802G protocol messages from other message types (Figure 61). The Datagrams are in 32-bit, big-endian format. The standard header fields are:

Byte 0	Byte 1	Byte 2	Byte 3
WSN802G Protocol Identifier = 0x52464D49			
Opcode		Transaction ID	
Data (variable length)			

Figure 61: WSN802G Application Protocol Datagrams use a Standard Header Beginning [52]

As information is formatted as IPv4 UDP/IP packets, the system can be used with a network protocol analyser such as Wireshark (Figure 62) that allows for capturing and interactive browsing of the traffic running on the network [55]. This allows examination of the various transmissions between the modules and server, such as Config traps and the transmissions that follow which are used to update the configuration of the WSN802G modules. This provides far more detailed information about the functioning of the WSN802G modules within the network.

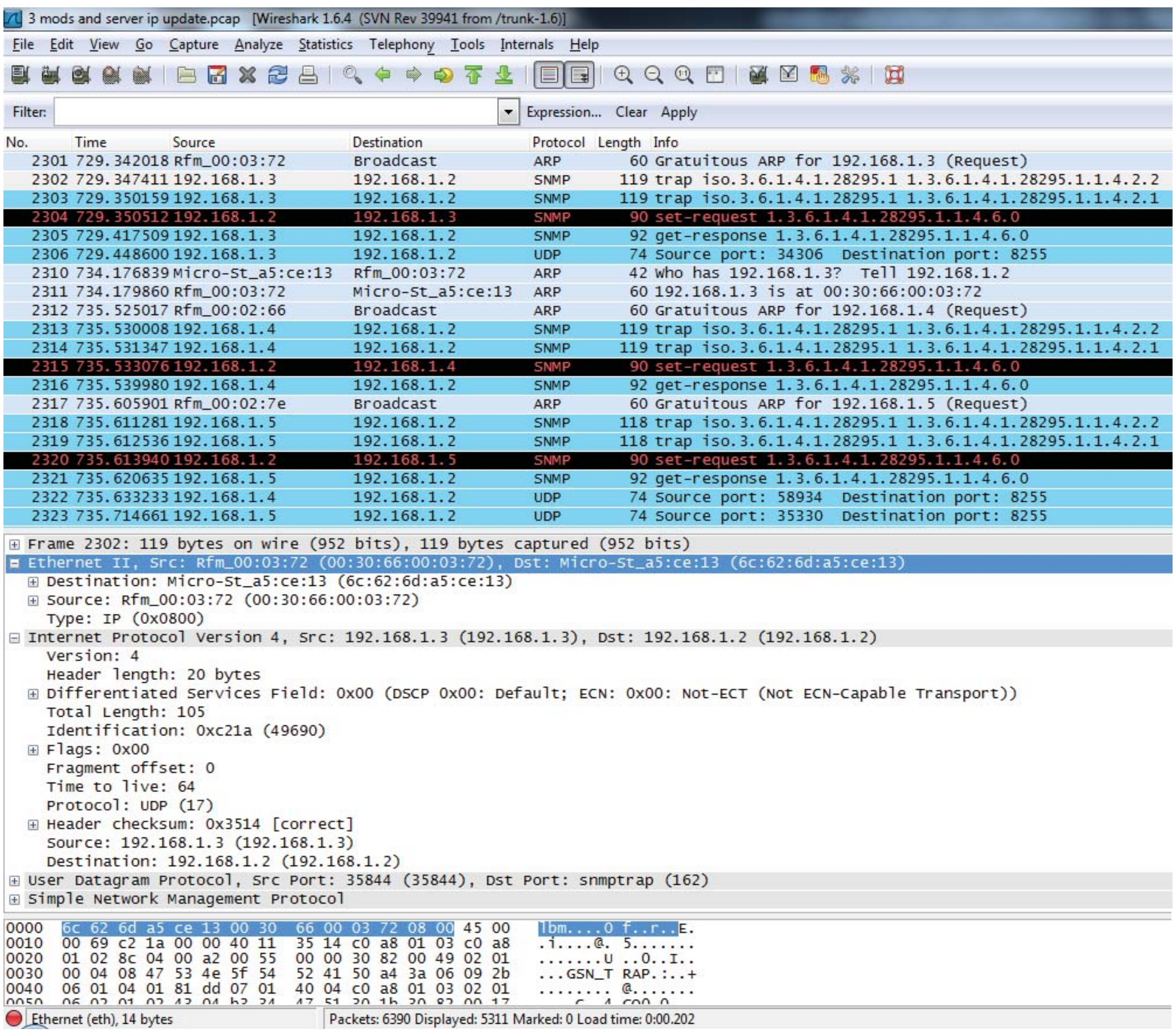


Figure 62: Capturing of Traffic Running on the Network with Wireshark Network Protocol Analyser

5.4.4. Acquiring IO Report Data from Wireshark Reading

In addition to seeing the occurrences of the Config traps, Linkup traps and IO reports within WireShark, it is possible to obtain data values for use in calculations (Figure 63) based on the information from the Datagram of I/O Report used for reporting of I/O values (Figure 58).

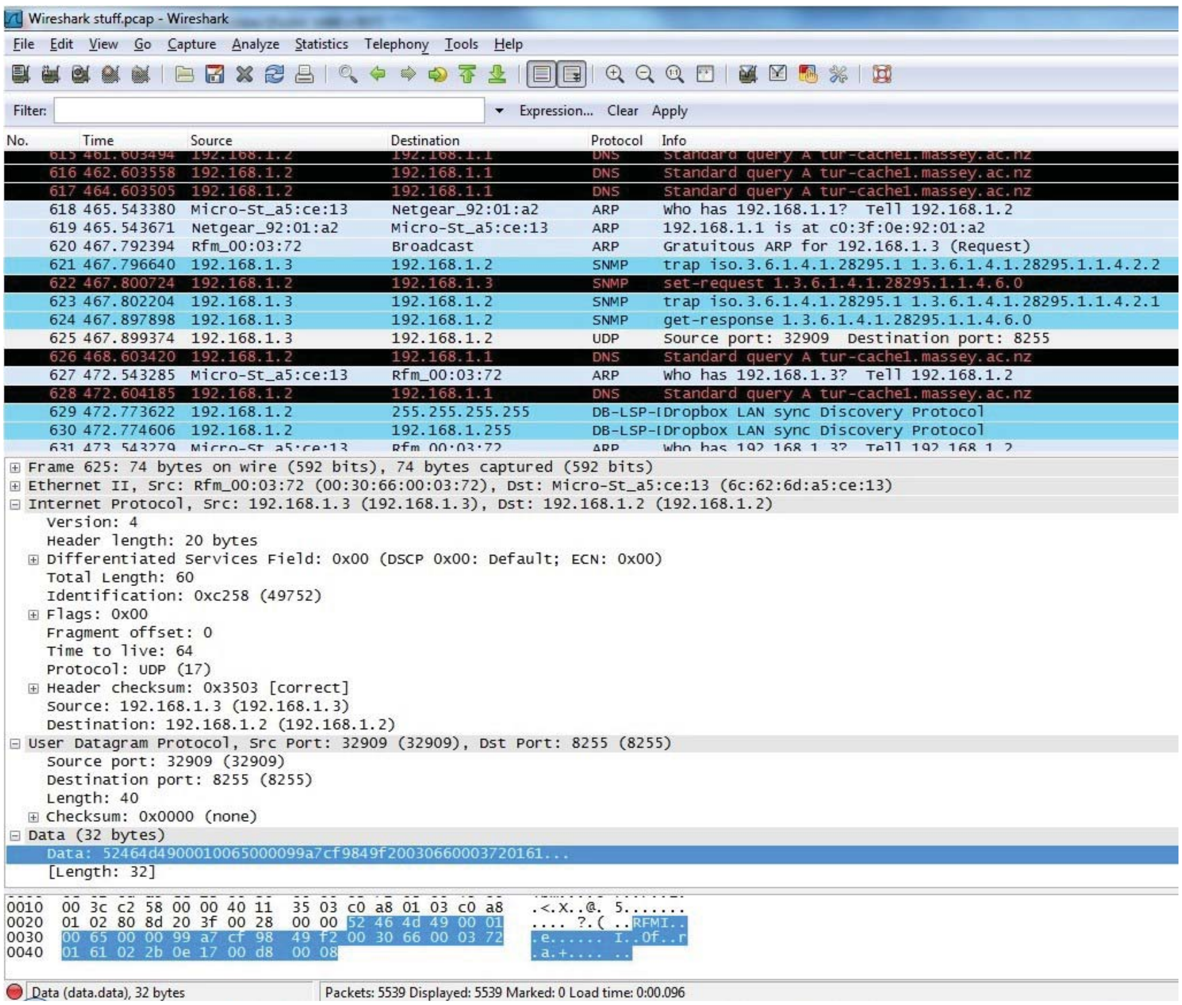


Figure 63: Use of WIRESHARK to Obtain IO Report Data

The following information was acquired through Wireshark, from the IO report while testing of WSN802G module within the Sensor network.

- Date and time Oct 27, 2011 11:02:27.176127000
- Data: 32 BYTES. HEX

- **0000** 52 46 4d 49 00 01 00 65 00 00 99 a7 cf 98 49 f2
- **0010** 00 30 66 00 03 72 01 61 02 2b 0e 17 00 d8 00 08

The 32 Bytes of data can be split as follows:

WSN802G Protocol identifier: The first four Bytes of information from the 32 Bytes of data is the protocol identifier to discriminate WSN802G protocol messages from other message types (Figure 61)

Protocol identifier Value: 52:46:4d:49

OpCode: The next two Bytes of data contains the OpCode which is the code indicating the type of command or response. As can be seen in (Table 8) the following value represents an IO_READ-IO_REPORT from Module to Server Transmission.

OpCode Value 00:01

Table 8: WSN802G OpCode for List of Transmissions [52]

Opcode	Direction	Description
0x0000	Server-to-Module	IO_READ_REQUEST
0x0001	Module-to-Server	IO_READ - IO_REPORT
0x0002	Server-to-Module	IO_WRITE_GPIO
0x0003	Server-to-Module	IO_WRITE_PWM
0x0004	Module-to-Server	IO_WRITE_REPLY
0x0005	Module-to-Server	IO_SERIAL_READ
0x0006	Server-to-Module	IO_SERIAL_WRITE
0x0007	Module-to-Server	IO_SPI_READ
0x0008	Server-to-Module	IO_SPI_WRITE
0x0010	Server-to-Module	CFG_READ
0x0011	Module-to-Server	CFG_READ_REPLY
0x0012	Server-to-Module	CFG_WRITE
0x0013	Module-to-Server	CFG_WRITE_REPLY

Transaction ID: The next two Bytes of data contain an incremental transaction reference counter, where each end of the link keeps its own counter for transactions that it originates.

Transaction ID Value: 00:65

Timestamp: The next eight Bytes of data contains Timestamp of reading in 7.62939 μs timer ticks since start up

Timestamp Value: 00:00:99:a7:cf:98:49:f2:

Mac Address: The next six Bytes of data contains the value for Mac Address of sender. As an IO_READ - IO_REPORT can be sent unsolicited, the MAC address is provided to identify the sender, in particular where DHCP is used and the IP address is initially unknown. The MAC Address of the sender is:

MAC Address Value: 00:30:66:00:03:72

ADC0: The next two Bytes contain the current ADC0 reading, where only the low 10 bits are significant

Value: 01:61

Bin= 101100001 Conversion to Binary

DEC=353 Conversion to Decimal

Noting that the

- ADC_REF is equal to 1.8V
- WSN802G uses a 10-bit ADC, hence ADCMAXVALUE = 2^{10} = 1023

Thus ADC0VALUE *ADC_REF/ADCMAXVALUE

= 353*1.8/1023

ADC0 = 0.621114V

Similarly

ADC1: The next two Bytes contain the current ADC1 reading, where only the low 10 bits are significant

Value: 02:2b:

Bin= 1000101011 Conversion to Binary

DEC= 555 Conversion to Decimal

Thus ADC1VALUE *ADC_REF/ADCMAXVALUE

= 555*1.8/1023

ADC1= 0.97654V

VOLT/Battery: The next two Bytes contain the current module voltage reading, 16-bit count in millivolts:

Value: 0e:17

Bin=111000010111

DEC=3607mV

Battery = 3.607V

RSSI: The next two Bytes Current RSSI reading, where only the lower one-byte value is of interest. The raw data is the 2's complement of the RSSI in dBm:

Value: 00:d8

BIN=11011000

As per RFM specification the RSSI Value is decreased by one to give the two's complement value of: 11010111

RSSI = -41dBm

GPIO: The remaining two bytes are GPIO values, where GPIO0 value is the right most digit, and GPIO1 is the second right most digit. The remaining digits are other GPIO values that may or may not be set as inputs at the time. Only GPIO lines defined as inputs are valid.

GPIO Value: 00:08

BIN=1000

Where GPIO0 and GPIO1 are inputs the above indicates their values are 0 and 0 respectively.

Using Wireshark we are able to obtain the following values based on the received UDP packet.

Table 9: Results Obtained from Wireshark for IO Report

TIME	**27-10-11 11:02:27**
SOURCE_IP_ADDRESS	192.168.1.3
SOURCE_MAC_ADDRESS	00:30:66:00:03:72
ADC0	0.621114
ADC1	0.97654
BATTERY	3.607
GPIO0	0
GPIO1	0
RSSI	-41

5.5. WI-FI DISTANCE TESTING

5.5.1. Experimental Setup

An experiment was carried out to test the reliability and feasibility of the Wi-Fi wireless communication. This experiment was carried out to reaffirm the statement made by the RFM regarding the performance of the WSN802G module 100 m outdoors/line of sight range [51]. Outdoor countryside was used as the test environment. Additionally the environment chosen was one where other networks were in close proximity (Figure 64) to see if any interference occurred.

Network Name (SSID)	Channel	N	WPS	Security	Signal	MAC Address
JUMA-PC_Network	1(G)	N	WPS	WPA2-PSK	89%	74:EA:3A:C1:53:3C
Thomson01F7F8	6(G)	N	WPS	WPA-PSK/WPA2-PSK	32%	00:26:44:01:F7:F8
WSN-Default	11(G)		WPS	WPA-PSK/WPA2-PSK	95%	C0:3F:0E:92:01:A2

Figure 64: Other Networks Running in Close Proximity to Sensor Network

The components required for the experiment are as follows:

- One WSN803G wireless module,
- One WSN802G Developers kit board. (Figure 65)
- A Wireless Router
- A personal computer
- A 9V alkaline battery

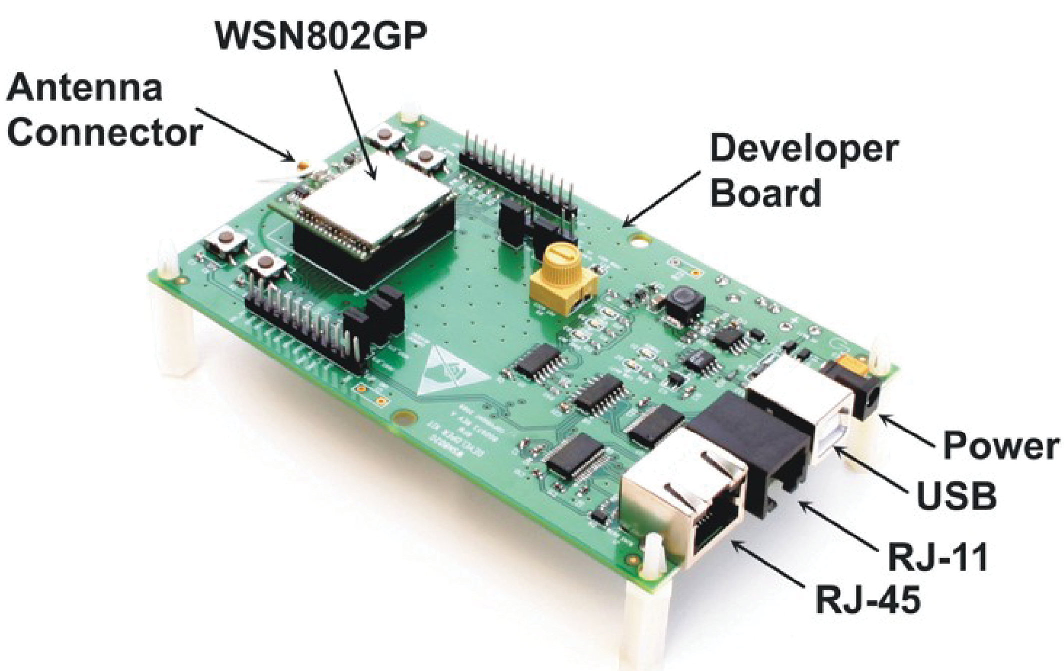


Figure 65: Developer Kit Board

The step by step setup of the experiment is as follows:

- Turn on Wireless Router and enable Wireless settings
- Connect Server (PC) to Router using either a wireless or wired connection
- Mount WSN802G module onto the Developers board
- 9V alkaline battery attached to power up the Developers board
- Configure WSN802G module for Server IP Address and desired Trap time interval and IO reporting

The testing procedure is reasonably straightforward. The experiment consisted of a series of tests to determine the distance attainable by Wi-Fi with respect to the change in displacement between the WSN802G Module and the Access Point (typically the distance was increased by 5m at the end of every test). With every test, twenty sample data packets were transmitted by the WSN802G module to the configured Server IP address. The reliability of the transmission is determined based on the number of received data packets with respect to the number of transmitted data packets. The results from the experiment are explained in following section

5.5.2. Experimental Results

In order to measure/obtain the data packets the WSNConfig program logging function was used for occurring trap times and IP address of originating trap in conjunction with Wireshark. The experimental results are shown in (Figure 66). As stated by RFM, the range of WSN802G wireless module is approximately 100m Outdoor [51]. The experiment proved this statement to be accurate. (Figure 66) shows the transmitted data packets were received in full at 100m and below. However, the communication drops significantly when the displacement increased above this limit. As the result, the number of packets received in comparison to those transmitted is reduced by a half at 110 m and totally at 115 m.

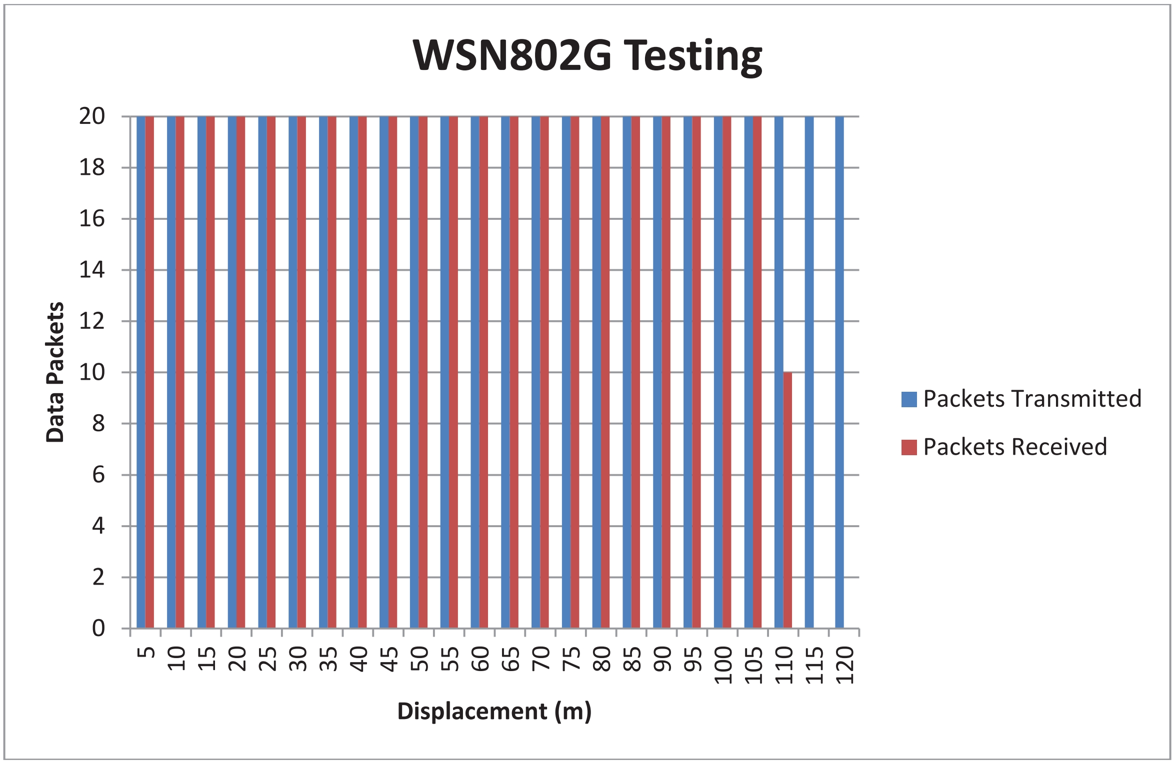


Figure 66: Testing Communication with Respect to the Changes in the Displacement between Module and Access Point

5.5.3. Discussion

Wi-Fi wireless transmission is considered to be very stable and reliable when operated within the recommended range. Wi-Fi was found to be very robust against external interferences. There were no significant signs of fluctuations in signal strength (RSSI) and it performed well even with other networks in the area (Figure 64) both at testing area and Massey University. In general, to ensure reliable data transmission it is recommended to limit the range outdoors at below 100m for clear line of sight.

6) MODULE INTEGRATION

6.1. DESIGN SPECIFICATIONS

It is important to specify the design specifications and requirements necessary for the development of the system before the system can be developed and implemented. This section explains the design specifications taken into account.

Server Requirements

The central station needs to be able to:

- Establish maintain and control the Wi-Fi network
- Send a data collection request to Sensor station
- Log incoming Data for storage
- Configure sensor node once put into field.

Sensor Station Requirements

The sensor station needs to be able to:

- Receive a data collection request from the coordinator station
- Collect data from the environment
- Perform analogue to digital conversion on the collected data
- Send IO Report packets to the Server station

Design Constraints

The following are the design constraints that need to be considered:

- The system must be compact and portable
- The system must have low power consumption
- The system must be reliable, robust and require little user interaction for collection of data
- Simple setup

- Adjustable times for communications and reporting
- Secure

6.1.1. Transceiver Unit

The WSN802G modules were used for communication between the sensor stations and the Central Server station. The WSN802G wireless module was designed to operate within the Wi-Fi wireless protocol where it provided a low cost, fast response and reliable solution for many type of wireless applications.

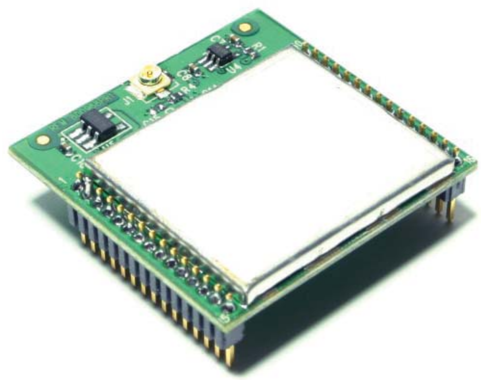


Figure 67: WSN802G 10mW Wi-Fi Module

Its main features [52][51] are listed as follows:

- Long Range Data Integrity
  - Indoor/Urban: up to 50 m
  - Outdoor line-of-sight: up to 100 m, upto 1Km with use of High gain antenna
- Transmit Power: 10 mW
- Data Rate: 1, 2, 5.5, 11 Mbps
- Receiver Sensitivity:
  - 1 Mbps RF Data Rate -92 dBm
  - 2 Mbps RF Data Rate -90 dBm
  - 5.5 Mbps RF Data Rate -84 dBm
  - 11 Mbps RF Data Rate -81 dBm
- FCC / IC / ETSI CERTIFIED

Advanced Networking & Security:

- DSSS (Direct Sequence Spread Spectrum)
- Point-to-Multipoint
- Ad Hoc mode for secure point-to-point capability
- 802.1x with RADIUS support
- WPA2-Enterprise security and WEP
- Sensor stations are able to support up to 4 network identifications (SSID), so the module has the ability to have up to 4 completely independent networks with separate security functions (Figure 68), allowing the node the ability to change to different routers as necessary

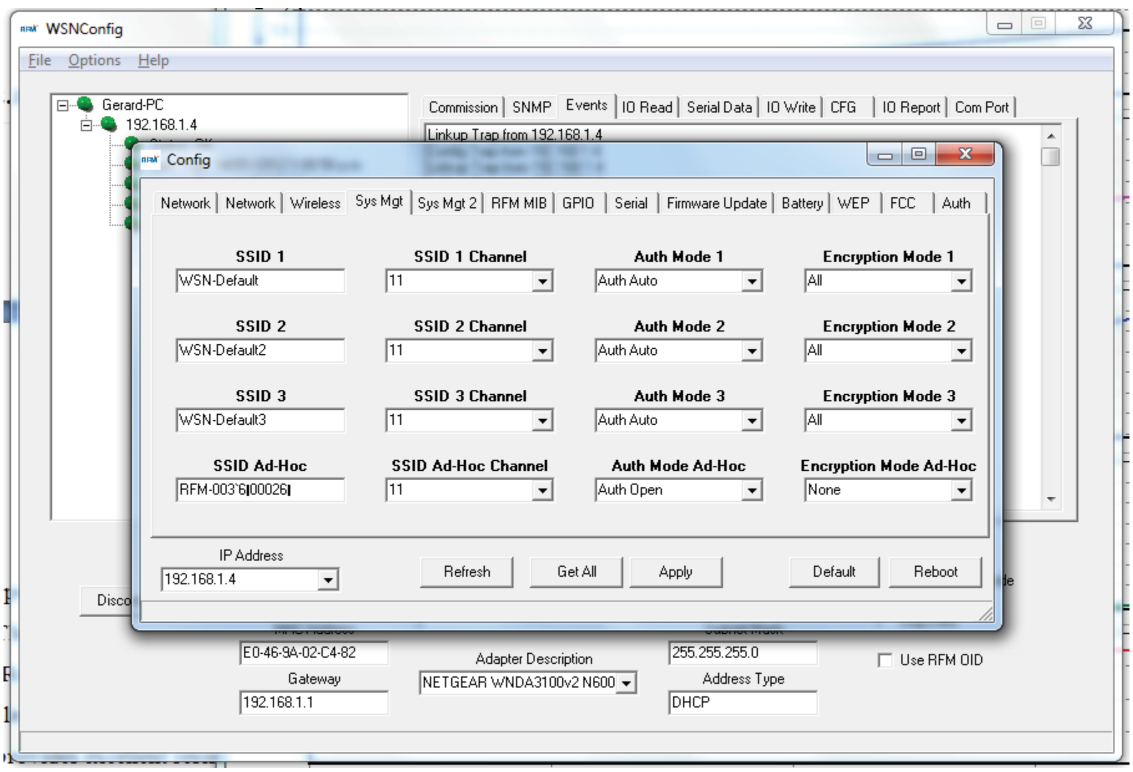


Figure 68: Allows Storage of Multiple Network Configurations

ADC and I/O line support:

- Analog-to-digital conversion
- General Purpose Input/Output (GPIO) ports

- Serial Peripheral Interface (SPI) Port
- Configurable automatic Reporting Includes
    - Interval timer
    - Interrupt
    - ADC level triggers

6.2. THE WI-FI BASED SYSTEM

Wi-Fi system has 3 different devices (Figure 69) - a Server that is responsible for establishing, maintaining and controlling the Wi-Fi network as well as logging of incoming data, the Router that takes care of data transmissions between server and sensor nodes and End Devices or sensor nodes that collect data and transmit them to the router which then sends it to the server.

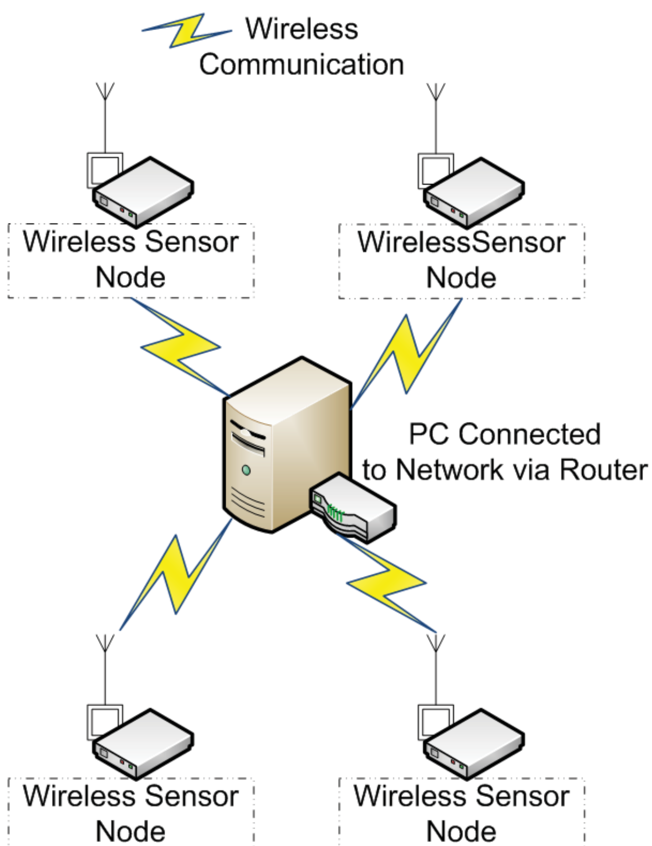


Figure 69: Concept of Wireless Monitoring of Agricultural Environment

6.2.1. The Server Station Setup

The Server Station Setup (Figure 70) has a PC connected to a standard wireless router via a Ethernet cable. However, if the PC has Wi-Fi that supports WPA2 encryption, no other cabling is required besides the router connection to a power supply. When connecting the Server PC via the wireless router, it is configured with a SSID of “WSN-Default” in secure mode operating on channel 11. In order to establish a wireless connection to the router, the PSK security passphrase to allow router access is “WSN-PASSWORD”.

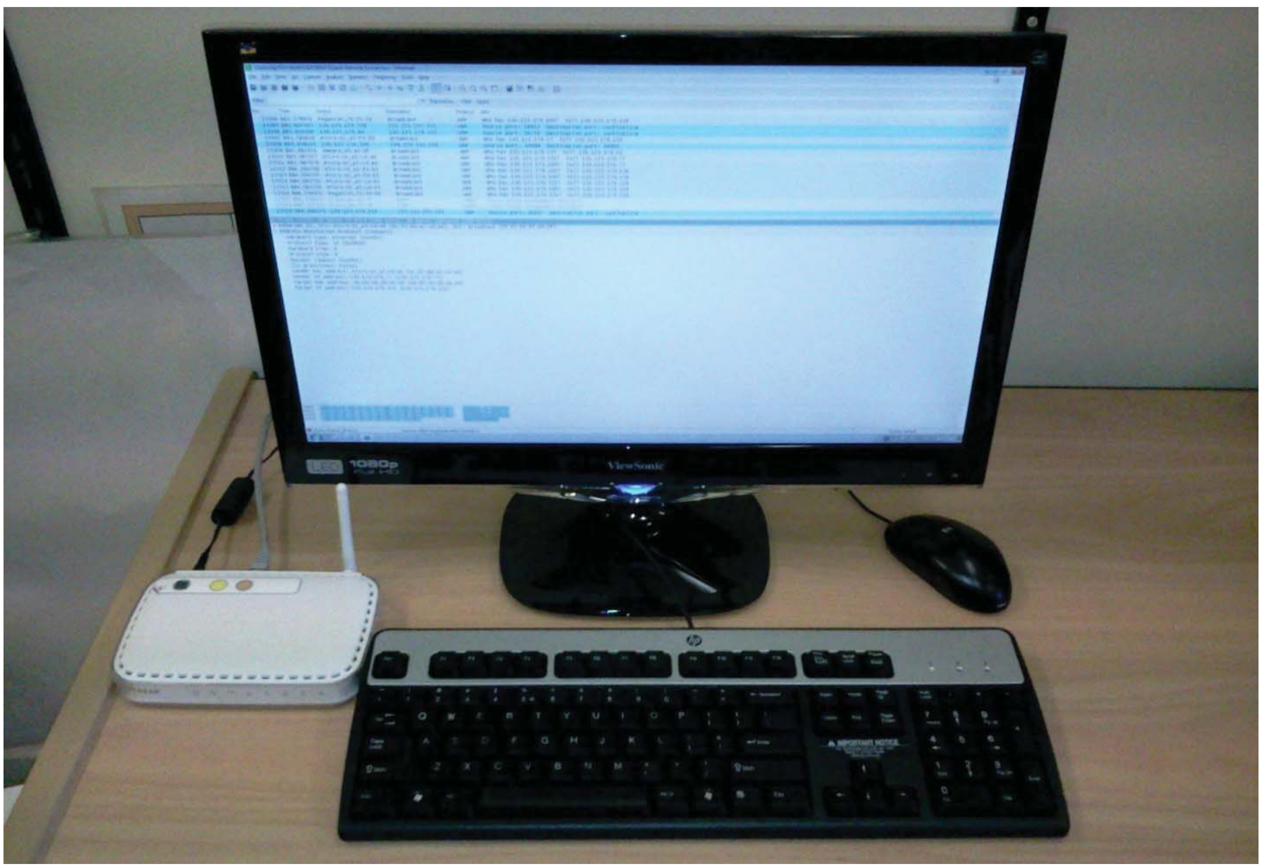


Figure 70: Layout of the Central Server and Router

The Server executes the WSNDemo sensor server application on Port 8255 to log data from sensor nodes. The Server can run the WSNConfig application as required in order to issue new configuration commands [52]. In addition all these applications can run in conjunction while running Wireshark for power users, who wish to have better inspection tools.

6.3. BATTERY LIFE OF SIMPLE WSN802G BOARD

During the early development stages of the Wi-Fi system the first iteration in Sensor Nodes contained a very simple test board where it was designed with a thermistor and Variable Resistor for ADC inputs (Figure 71). Where the ADC_REF_OUT pin of the WSN802G provides a 1.8V reference voltage for the resistor divider setup of 10K ohm resistor R1, and the 10K thermistor RT1 (Figure 72).

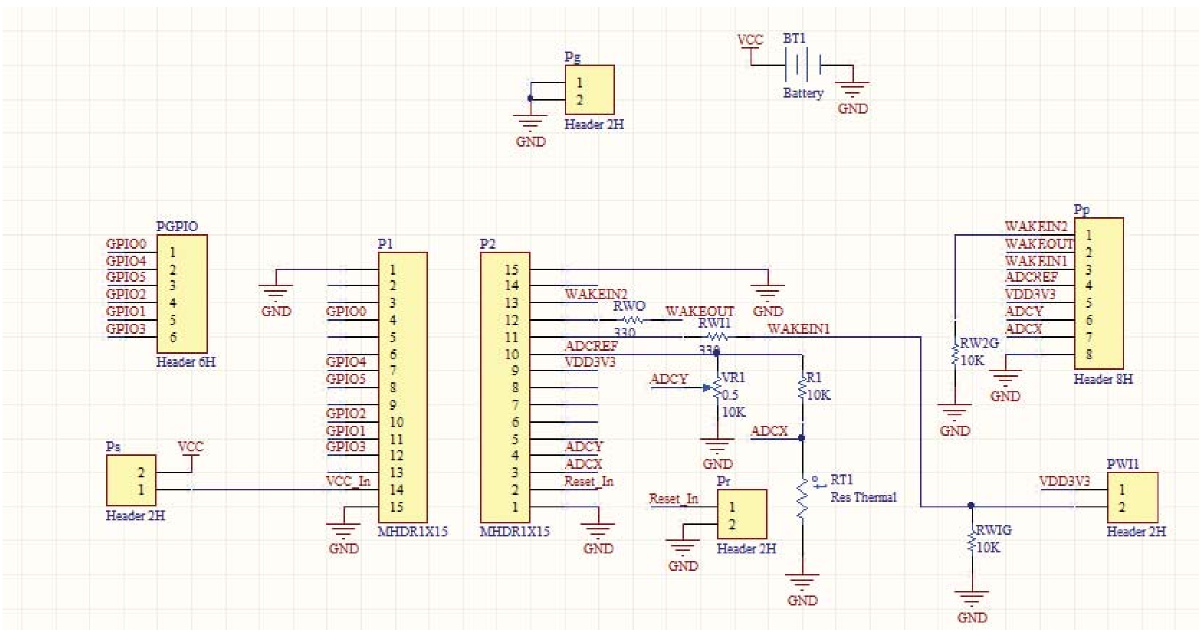


Figure 71: The WSN802G Simple Test Board Circuit Schematic

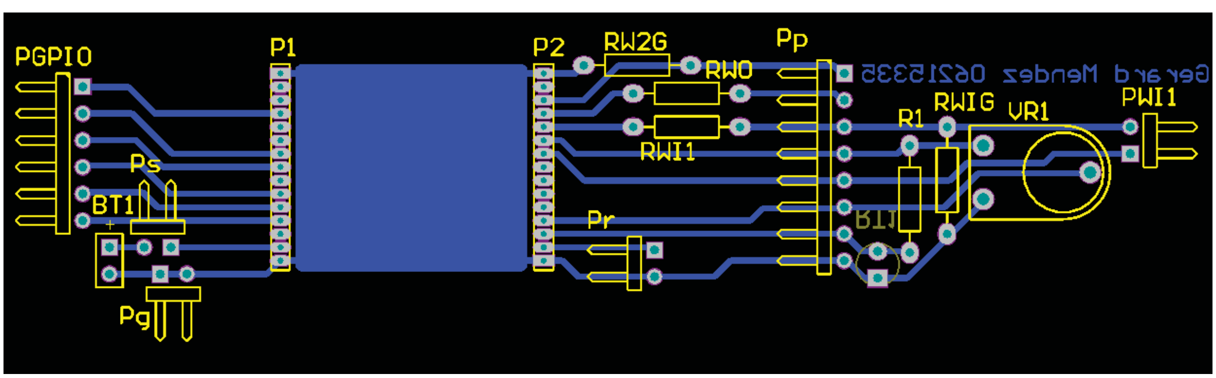


Figure 72: The WSN802G Simple Test Board PCB Design

Using this simple test board it was discovered that, at the IOreport and Linkup up trap every 10Sec, and Config trap every 20Secs, the lifespan of 2 AA batteries is approximately 9.5 days before it stops communicating (Figure 73).

This result indicates that the WSN802G developed system is both energy efficient and cheap to operate. The module continues transmitting at a battery voltage of approximately 2.6V. Longer life can be expected by longer intervals between IOReport, Linkup trap and Config trap or using larger capacity batteries.

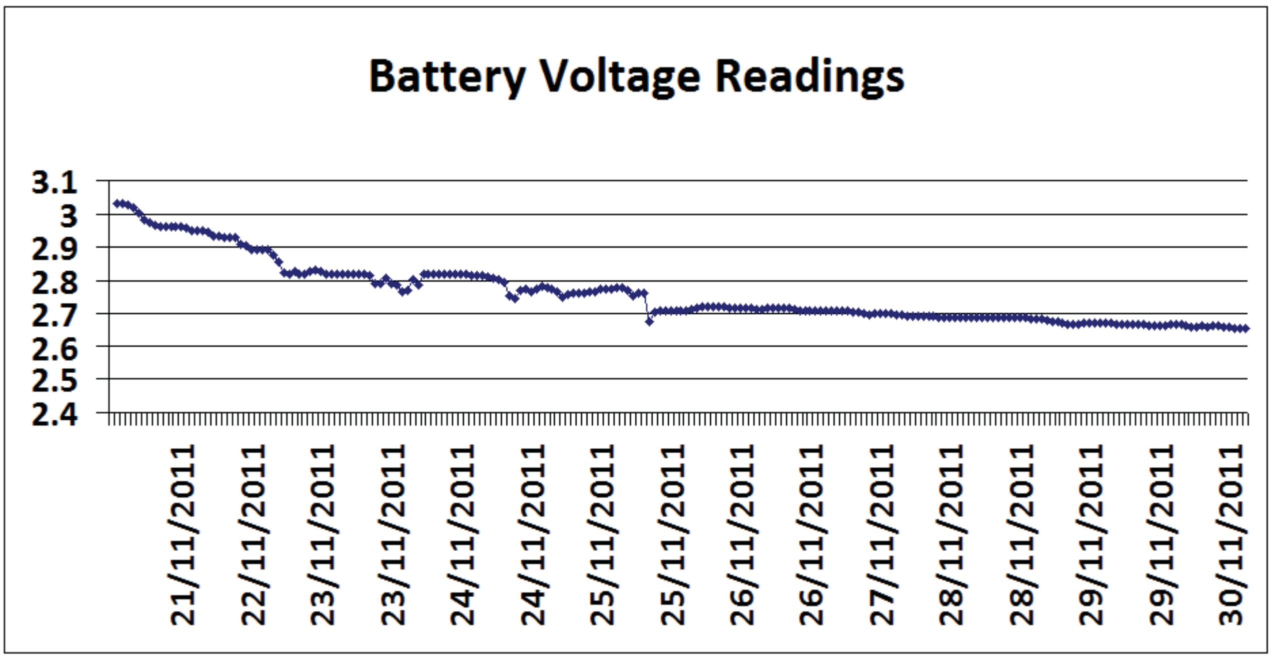


Figure 73: Battery Voltage Reading over Various Days

These results also helped to confirm that the expected value of module operation matches the battery level configuration for modules (Figure 74) where minimum boot up battery level is set to 2600mV or 2.6V.

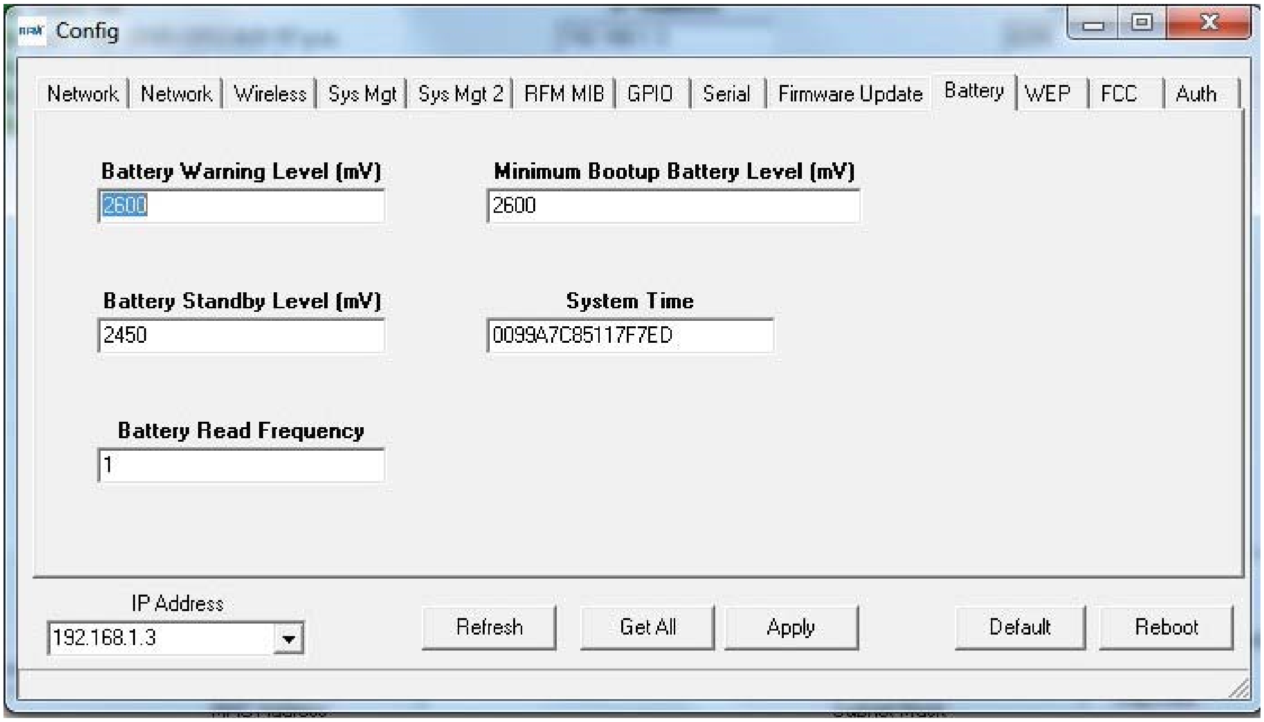


Figure 74: Battery Level Configuration for Module

6.4. TESTING ENERGY CONSUMPTION

In order to test energy consumption of the WSN802G module the simple test board (Figure 72) was connected in series to a 1.055 ohms resistor and to a DC Power supply (Figure 75). Using a Tektronix TDS2024C oscilloscope, the voltage drop over the resistor was measured. Since the value of the resistor and the voltage are known, circuit current can be calculated (6.4.1) using values given by the oscilloscope. A small resistance value was chosen so as to minimize additional voltage drop. The Oscilloscope was used as it measures short duration signals in different frequencies. This is particularly important as signals/pulses will be short in duration (msec). Most voltmeters are calibrated to measure signals in DC or AC only, and averaging would not provide adequate results.

$$V = \mathrm{I} \times \mathrm{R} \quad \textbf{(6.4.1)}$$

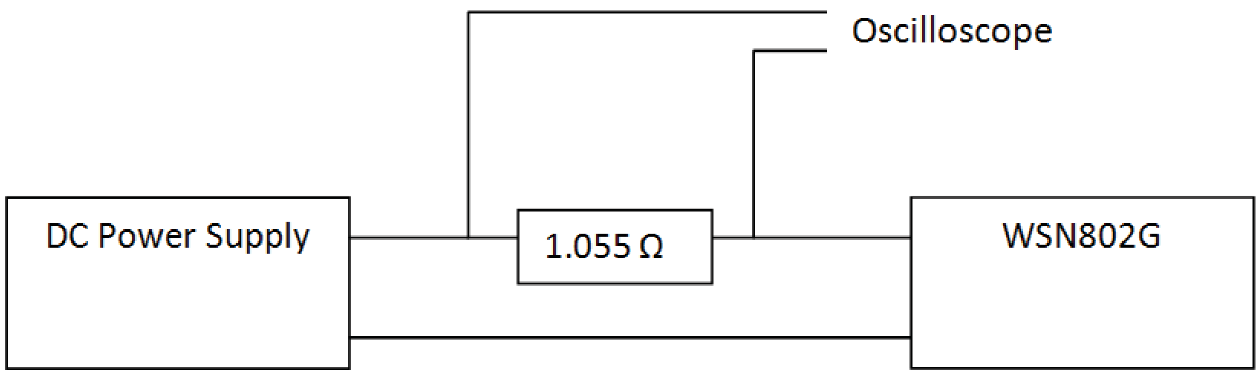


Figure 75: Connection for Voltage Measurements

The above configuration (Figure 76) demonstrates energy consumption of the node in response to several states: Linkup Trap + IOReport (Figure 78), Config Trap + Linkup Trap + IOReport (Figure 79) and when the node is set to Always Awake (Figure 77).

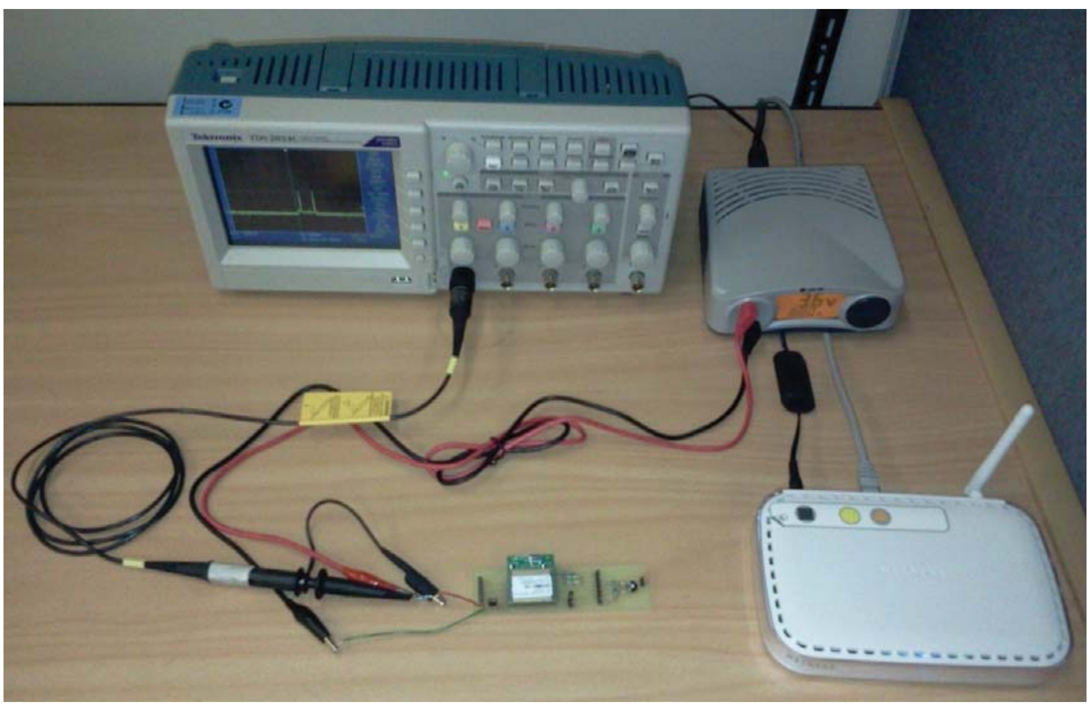


Figure 76: Configuration for Testing for Power Consumption

The default state of the WSN802G is sleep mode in which the WSN802G module draws very little current [52]. The following are events that will wake the WSN802G from sleep mode:

- Applying a logic high signal on the WAKE_IN pin
- Expiration of the AutoReport timer
- Expiration of Linkup trap timer
- Expiration of the Config trap timer

6.4.1. Always Awake Tests

Using these waveforms it was possible to identify the periods when a module was awake, transmitting, the transmission time and peaks of current consumption.

Starting with the WORST but unlikely scenario, we have the Node constantly active in “Always Awake” mode and energy saving settings such as the sleep mode are not utilised.

Figure 77: The Voltage Signal when Always Awake

Energy consumption measurements were performed for the Module while in “Always Awake” and the summary is seen in (Table 10) and (Table 11).

Table 10: Voltage over the Resistor

Always on Voltage Readings	
Min	139.02mV
Mean	173mV
Max	**221.84mV**

Where Current was calculated based on $I = \frac{V}{R}$

Table 11: Current through Circuit

Always on current	
Min	131.77mA
Mean	163.98mA
Max	**210.27mA**

For the Power consumption

$P = V \times I$ **(6.4.2)**

Voltage in the transmitting node = 3.031V

MaxPower =3.031V*210.27mA = 637.33mW

Using maximum measured values (worst case) for voltage (Table 10) and current (Table 11) energy consumed by a module can be illustrated using the following procedure:

$\text{Energy} = W \times t$ **(6.4.3)**

$\text{Energy} = V \times I \times t$ **(6.4.4)**

Where t is time in seconds

Using max value

3.031 x 0.21027 x t = 0.6373 x t (joules)

If one hour i.e. 3600secs

0.6373 x 3600 = 2294.28 Joules

It was found that in one hour, the application would consume 2294.28 Joules of energy if the module did not enter power saving sleep mode.

6.4.2. Link Up and IO Report Tests

Energy consumption measurements were gathered on the module when operating normally as seen in the LinkupTrap/IO Report (Figure 78). The summary can be seen in (Table 13) and (Table 14).

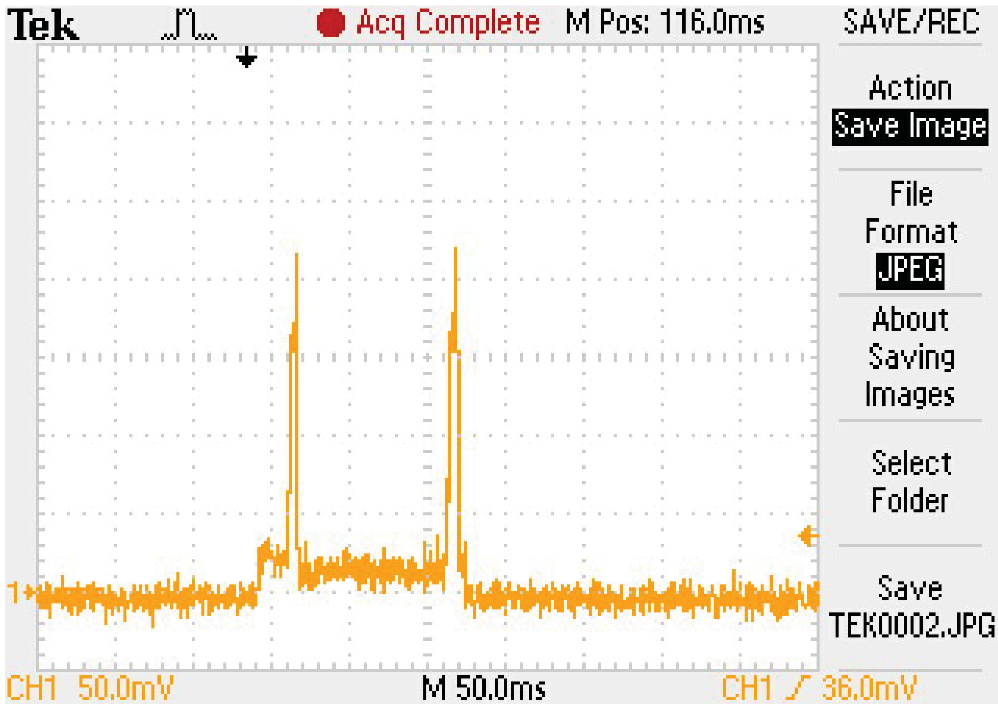


Figure 78: The Voltage Signal when a Linkup Trap and IO Report are Sent

The oscilloscope was used to take measurements at various RSSI values which were then averaged as seen in (Table 12).

Table 12: Measurements taken at Different RSSI Values for Linkup Trap and IO Report

RSSI Value	Active Time (ms)	Peak time (ms)	Highest Peak (mV)	Non peak active voltage (mv)
-25dBm	136.25	25.45	221.9	22.15
-50dBm	137.5	23.8	222.5	23.31
-65dBM	137.55	25.05	221.8	23.45
Average	137.1	24.77	222.07	22.97

Using the oscilloscope it is found the Linkup trap/IO report had an average awake time of 137.1ms

Where:

- Average peak time represents the proportion of time the module was on and transmitting: 24.77ms
- Average time for non peaks represents proportion of time the module is awake but not transmitting: 112.33ms

When a Linkup and IO Report occurs it can be split into the following:

- 18.07% Time it is Transmitting
- 81.93% Time it is awake but not transmitting:

Table 13: Voltage Over the Resistor Linkup Trap and IO Report

Average Peak Max:	222.07mV
Average Non Peak:	22.97mV

Where I =V/R

Table 14: Current through Circuit Linkup trap and IO Report

Average Peak Max:	210.49mA
Average Non Peak:	21.77mA

The voltage measure in the transmitting node was 3.021V as it is possible to calculate power values (Table 15) during peaks and non peaks where P=VI

Table 15: Calculated Power Values Consumption Linkup Trap and IO Report

Power during Peaks	635.89mW
Power during Non Peaks	65.77mW

From the results in (Table 13) and (Table 14), it is possible to find energy consumed by one module during this Linkup and IO Report scenario using the following procedure:

Energy per Linkuptrap/IO report= [PeakPower x (AverageAwake time x %PeakTime) + NonPeakPower x (AverageAwake time x %NonPeakTime)]

Energy per Linkuptrap/IO report = 0.02314 (joules) = 23.14 (mjoules)

6.4.3. Power for Config, Linkup trap and IO Report Tests

Energy consumption measurements were gathered on the module when it operates normally and sends a ConfigTrap/LinkupTrap/IO Report (Figure 79). The summary can be seen in (Table 17) and (Table 18).

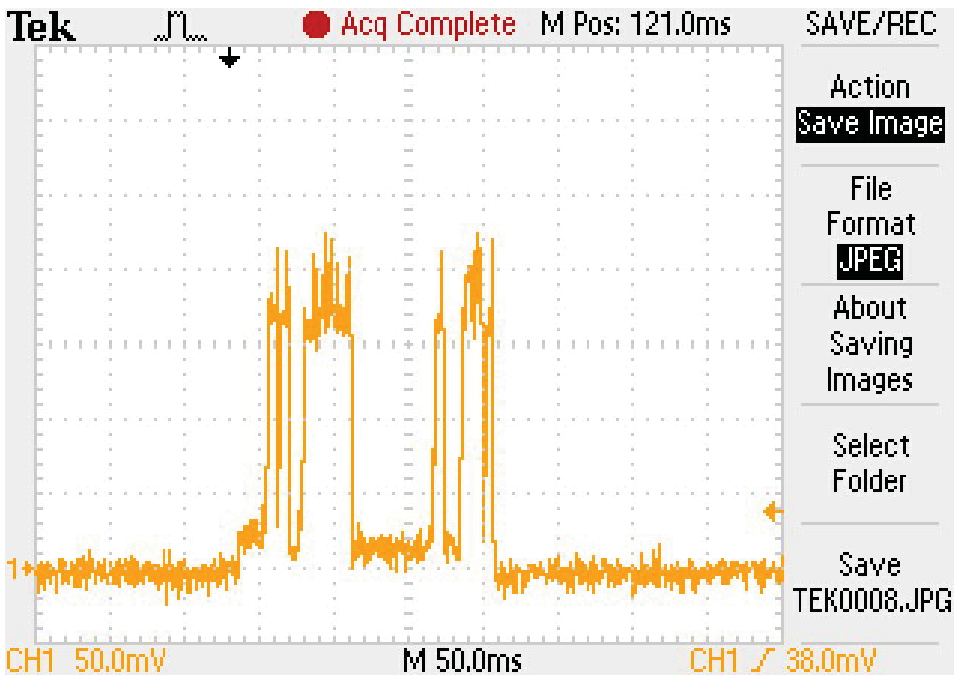


Figure 79: The Voltage Signal when Config Trap, Linkup Trap and IOReport are Sent

The oscilloscope was used to take measurements at various RSSI values which were then averaged as seen in (Table 16).

Table 16: Measurements Taken at Different RSSI Values For Config, Linkup and IO Report

RSSI Value	Active Time	Peak time (ms)	Highest Peak (mV)	Non peak active voltage (mv)
-25dBm	164.95	89.75	233.35	22.15
-50dBm	183.9	102.35	229.9	23.31
-65dBM	189.1	103.05	231.8	23.45
Average	179.31	98.38	231.68	22.97

Using the oscilloscope, it is found the Config, linkup and ioreport traps took on: average Awake time: 179.31ms

Where:

- Average peak time represents the proportion of time the module is on and transmitting: 98.38ms
- Average time for non peaks represents proportion of time the module is awake but not transmitting: 80.93ms

So when a Config, Linkup and IO Report occurs, it can be split into the following:

- 54.87% Time it is transmitting
- 45.13% Time it is awake but not transmitting:

Table 17: Voltage over the Resistor Config, Linkup and IO Report

Average Peak Max:	231.68mV
Average Non Peak:	22.97mV

Table 18: Current through Circuit Config, Linkup and IO Report

Average Peak Max:	219.6mA
Average Non Peak:	21.77mA

The voltage measure in the transmitting node was 3.021V as it is possible to calculate power values (Table 19) during peaks and non peaks where P=VI

Table 19: Calculated Power Values Consumption Config, Linkup and IO Report

Power during Peaks	663.41mW
Power during Non Peaks	65.77mW

From the results in (Table 17) and (Table 18), it is possible to find energy consumed by one module during this Config, Linkup and IO Report scenario using the following procedure:

Energy per Config/Linkuptrap/IO report= [PeakPower x (AverageAwake time x %PeakTime) + NonPeakPower x (AverageAwake time x %NonPeakTime)]

Energy per Config/Linkuptrap/IO report = 0.07061 (joules) = 70.61 (mjoules)

6.4.4. Hourly Energy consumption for WSN802G

So, energy consumption for this WSN802G application in one hour, can be calculated (6.4.5) by adding the values previously calculated in addition to sleep power consumption where the calculated energy used in sleep mode was based on voltage supply of 3.21V and Sleep Mode Current = 7.5uA as per datasheet [52].

$$\text{Energy} = 23.14\text{m} \times \text{tL} + 70.61\text{m} \times \text{tC} + 24.08\text{u} \times \text{t} \quad (6.4.5)$$

Where:

- tL is the number of occurrences of linkupTrapTimer/AutoReport timer in a period of time
- tC is the number of occurrences of Config timer in a period of time
- t is the period of time

If the following assumptions are made for Trap and IO intervals, the quickest interval time desired might be where LinkupTrapTimer and AutoReport timer are set to 5second and ConfigTrapTimer is 10seconds.

Table 20: Assumptions made for Trap and IO Intervals

Linkup Trap	5sec
Config Trap	10sec
Report Trap	5sec

If period of an hour = 3600seconds and the LinkupTrapTimer_AutoReport timer =5sec then tL=3600/5 where LinkupTrapTimer_AutoReport will occur 720 times in an hour. ConfigTrapTimer_AutoReport timer =10sec then tC=3600/10 i.e. ConfigTrapTimer will occur 360 times in an hour. Then in one hour energy consumption can be calculated as =42.17Joules

6.4.5. Calculation of Expected Lifetime

Using the energy consumption rate previously calculated, it is possible to estimate sensor node lifetime. The following calculations show use of approximate energy consumption of the node, together with the discharge curve of the battery in order to estimate its lifetime.

Using the energy consumption calculated as =42.17Joules it is possible to calculate Watt-hour (6.4.6).

$$\text{Energy} = \text{Power} \times \text{Time} \qquad (6.4.6)$$

$$42.17J = 0.01171W \times 3600s = 0.01171Wh$$

The following equation (6.4.7) gives energy consumption in mAh using Watt-hour and voltage for the node of 3V.

$$E(t) = \text{watt-hour} \times 1000 \div V \qquad (6.4.7)$$

E(t) = 3.9 mAh

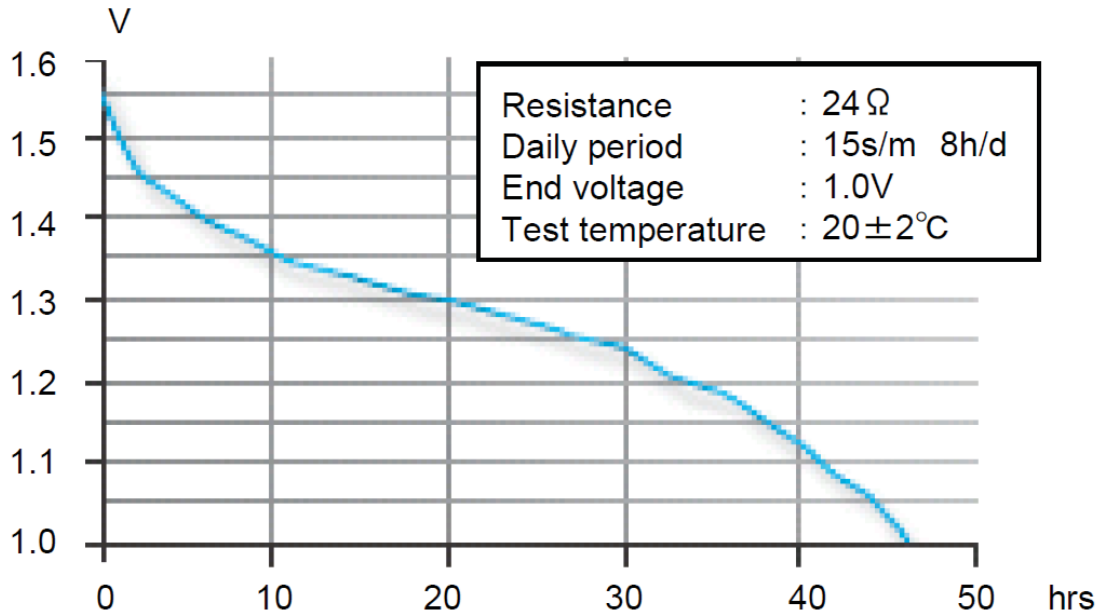


Figure 80: A Typical Discharge Curve Panasonic AA Battery Datasheet [56]

Analyzing the battery discharge curve shown in (Figure 80)[56], the curve remains at or above the required 1.3V per cell; when the battery has spent approximately 44% of its capacity, the voltage drops below required voltage. Applying this criterion to capacity C of the battery, an expression for lifetime can be obtained (6.4.8): where a capacity of 1000mAh was used for alkaline batteries.

L = 0.44 x C ÷ E(t) **(6.4.8)**

The battery lifetime calculated is 112.82hrs or 4.7 days, which as expected is half as long as measured in the test case (Figure 73) where there were half as many communications occurring in an hour.

If recalculated using tests values for LinkupTrapTimer_AutoReport timer and ConfigTrapTimer_AutoReport, then in one hour energy consumption can be calculated as

=21.13Joules and calculated lifetime is 224.9 hrs or 9.347 days, similar to obtained tests performed (Figure 73).

6.4.6. Evaluation

The test conducted seems to confirm the WSN802G values for transmit mode current of about 200 mA. It also confirms that Config trap activity requires a significant amount of energy to execute, and for battery-powered deployments the Config trap interval should set this interval to once an hour or a few times per day to conserve battery life. This is likely due to the fact that upon a Config trap, the module awaits for the server to send ConfigComplete command to indicate it has finished sending commands or that it has no commands to send. Based on this results indicate that the WSN802G module is quite energy efficient. If the system is battery operated a longer life time can be expected by having longer intervals between IOReport, Linkup trap and Config trap as well as using larger capacity batteries. It is possible to estimate a node's expected lifetime, the difference between expected and actual values being quite small.

6.5. WSN SENSOR NODES POWER OPTIONS

6.5.1. Introduction

As with any electronic device WSN requires power for operation. This is especially true with regards to sensor nodes that require energy to fulfil its desired role. Although there are certain situations where mains power might be available such as the hydroponics green house, this will not always be the case. So, other methods have been investigated for powering WSN nodes which include batteries [57], energy harvesting [58] and active power supplies [59].

6.5.2. Battery Investigation

Batteries are commonly utilized as power sources for WSN nodes [57][60][59]. However, batteries can emit a limited amount of energy before they are depleted. To address this issue, energy harvesting techniques can be employed [59][58]. Energy harvesting allows nodes to replenish depleting energy sources such as batteries from external sources. Such energy harvesting helps to deal with the cost and problems associated with replacing and disposing of batteries. Investigation was performed into various types of batteries in the following section.

Alkaline Batteries

Alkaline Batteries are one of the most commonly used household battery and they are well known for their long shelf life. However, standard alkaline batteries are not suited for use in high-drain devices [61] and are not rechargeable. There are alkaline rechargeable batteries, but they are generally of lower capacity and offer fewer recharge cycles than the other popular rechargeables [61]. However, rechargeable alkalines have a lower self-discharge rate and are able to sit on the shelf between periods of use. One advantage of alkaline batteries is that neither type contains toxic metals [62], and both types can be disposed easily.

Lithium-ion

Lithium-ion batteries are the batteries often used in high-drain devices such as laptops and cell phones. The lithium-ion battery has a good power to rate ratio [61]. Lithium ion batteries are usually recharged in specialised rechargers where safety requirements such as mandatory protection circuits are needed and internal protection circuits typically consume 3% of the stored energy per month [63].

A few disadvantages of lithium batteries are that they contain toxins and require disposal at a hazardous waste station [61], have low overcharge tolerance and cannot tolerate trickle voltage [64]. The lithium plating in the batteries is also known to be more vulnerable to failure if exposed to vibration or other stressful conditions [65]. For example while other battery types can tolerate extreme temperatures occasionally, there are limitations with Li-ion. Safety concerns indicate that Li-ion should remain within its specified limits due to possible thermal runaway if stressed [65]. In particular Li-ion in presence of elevated temperatures hastens permanent capacity loss (Table 21).

Table 21: Permanent Capacity Loss of Lithium-Ion as a Function of Temperature and Charge Level [66]

Battery Temperature	Permanent capacity loss when stored at 40% state-of-charge (recommended storage charge level)	Permanent capacity loss when stored at 100% state-of-charge (typical user charge level)
0°C	2% loss in 1 year; 98% remaining	6% loss in 1 year; 94% remaining
25°C	4% loss in 1 year; 96% remaining	20% loss in 1 year; 80% remaining
40°C	15% loss in 1 year; 85% remaining	35% loss in 1 year; 65% remaining
60°C	25% loss in 1 year 75%; remaining	40% loss in 3 months

Nickel-Cadmium (NiCad)

NiCAD rechargeable batteries are now nearly obsolete. In comparison with other rechargeable batteries they have lower capacity in addition to containing toxic metals that involve hazardous waste disposal [62]. NiCAD batteries are also said to suffer from the 'memory effect', referring to recharging where, the battery 'remembers' the point at which it was recharged previously and will not become fully charged again. NiCADS are more prone to steep drops in power when they are ready to be recharged [61].

Nickel-Metal Hydride (NiMH)

NiMH rechargeable batteries have replaced the NiCAD with their higher capacity. It is easy to dispose of since it does not contain toxic metals and isn't classed as a hazardous waste item [62]. The disadvantages of NiMH are less voltage than alkaline batteries [67]. The NiMH comes in different capacities where High capacity NiMH batteries may not charge completely in some chargers. Additionally they self-discharge at a high rate. Shelf life is short and can be prone to steep drops in power when they are ready to be recharged [61][68].

Lead Acid

One of the oldest rechargeable battery systems is known for being quite economical in price, rugged, and forgiving if abused [63] particularly a high over charge tolerance [69] as well as being reasonably forgiving when it comes to temperature extremes [65]. Lead acid batteries should avoid deep discharges and be charged more often. It can stay on charge with correct float charge [64]. A disadvantage is that a deep-cycle battery delivers a 100–300 recharge cycles [67][69] before it starts a gradual decline in capacity. Other disadvantages include size and weight of batteries and the toxic material contained.

6.5.3. Comparison of Batteries

A good battery must be able to provide power demand by supplying adequate voltage and current when needed. In addition, it needs to be economical, easy to recharge and have a good capacity with the ability to last a long time.

This system would do well with a harvest type, therefore rechargeable batteries are investigated. Among the rechargeable batteries are Lead Acid and Li-ion based on the battery comparison (Table 22) Although Li-Ion has a higher value for Watt-hours/litre it has a disadvantage in cost [63]. This is due to the manufacturing cost being higher and therefore these batteries are higher priced than the other types of rechargeable batteries.

Table 22: Comparisons of Price and Energy Density of Batteries [70]

Battery Type	Cost $ per Wh	Wh/kg	Joules/kg	Wh/liter
Lead-acid	$0.17	41	146,000	100
Alkaline long-life	$0.19	110	400,000	320
Carbon-zinc	$0.31	36	130,000	92
NiMH	$0.99	95	340,000	300
NiCad	$1.50	39	140,000	140
Lithium-ion	$0.47	128	460,000	230

Lead acid Batteries are reasonably robust and forgiving when it comes to temperature extremes and are still able to function. It has greater charging tolerances [65] Lead acid batteries work well where deep discharges are avoided and are charged more often, a situation that is present in certain energy harvesting situations.

The disadvantages of Lithium batteries make the Lead Acid Battery a good choice for further investigation.

6.5.4. Energy Harvesting

As batteries have limited amounts of energy that can be utilized, it is of interest to address such issues with implementation of energy harvesting techniques [59][58]. Energy harvesting allows replenishing of depleted energy sources from external sources. Investigation was performed researching various energy harvesting systems as discussed in the following sections.

Solar

Solar panels convert sunlight into electricity and have the ability to provide power to run most wireless sensor node applications [57] where the use of incident light to generate power has been well established. The power available from solar cells varies widely depending on the intensity of the sun. Sunlight is limited to a certain period of time each day. Additionally a number of other factors reduce the attainable power. Cloud cover and shadowing may block the sun's rays. Therefore, some form of secondary storage, such as batteries, would be required for sensor nodes to continue operating effectively.

Solar allows for a more portable system than wind power as it requires a lower height. However, a tracking system is required to follow the optimal angle of the sun. Research is required before the process becomes more cost-effective ($9-10/Watt) than some alternative energy sources [71].

Wind

Wind turbines consist of blades, rotors, gears, generator and electronics. Wind turbines with use of its blades, convert kinetic energy from wind. The turbine turns this rotational energy into power via the generator. Availability of wind resources can vary based on geographical and topical features. Wind energy has lower cost ($5-6/Watt) in comparison to some other alternative energy [71]. Incremental improvements in wind technology have allowed for more reliable systems where wind turbines worldwide have generated as much electricity as conventional power plants [72]. A disadvantage of wind power is the requirements for blades to be elevated in order to catch the force of the wind. Wind turbines have multiple moving parts where wear and tear can occur.

Laser Remote Power Supply System

One novel power supply system that has seen some implementation recently is the use of lasers to supply power remotely to multinode wireless sensor networks [59]. This is done by transforming light from a laser to a wavelength that solar cells can utilize. Experiments have been carried out, where the system has been able to supply 92.1 mJ during 0.7 s which can provide enough energy for a WSN node. In addition, the system has been used in real-life applications, such as in an oil cellar [59]. As a novel power supply method for wireless sensor networks, it appears to be a good power supply candidate for wireless sensor networks. However, it would be too expensive and impractical to implement.

RF Energy Harvesting

The harvesting of RF energy is possible with the use of a wireless power module combined with RF energy-harvesting technology and a supercapacitor in an attempt to create a battery-free power source for wireless sensors in certain conditions [58]. Certain commercially available RF energy harvesting systems are available for easy connection to wireless modules (Figure 81). The system consisting of the wireless module can be integrated with a power receiving antenna, a powerharvester to convert the radio waves into low DC power and a CAP-XX supercapacitor [58][73]. The supercapacitor stores the harvested energy and provides peak transmission power to a wireless sensor/transmitter board.

Efforts have been made to harvest environmental radio waves from TV, radio or mobile phone networks while keeping a small form factor and simple hardware integration for any RF module [60].

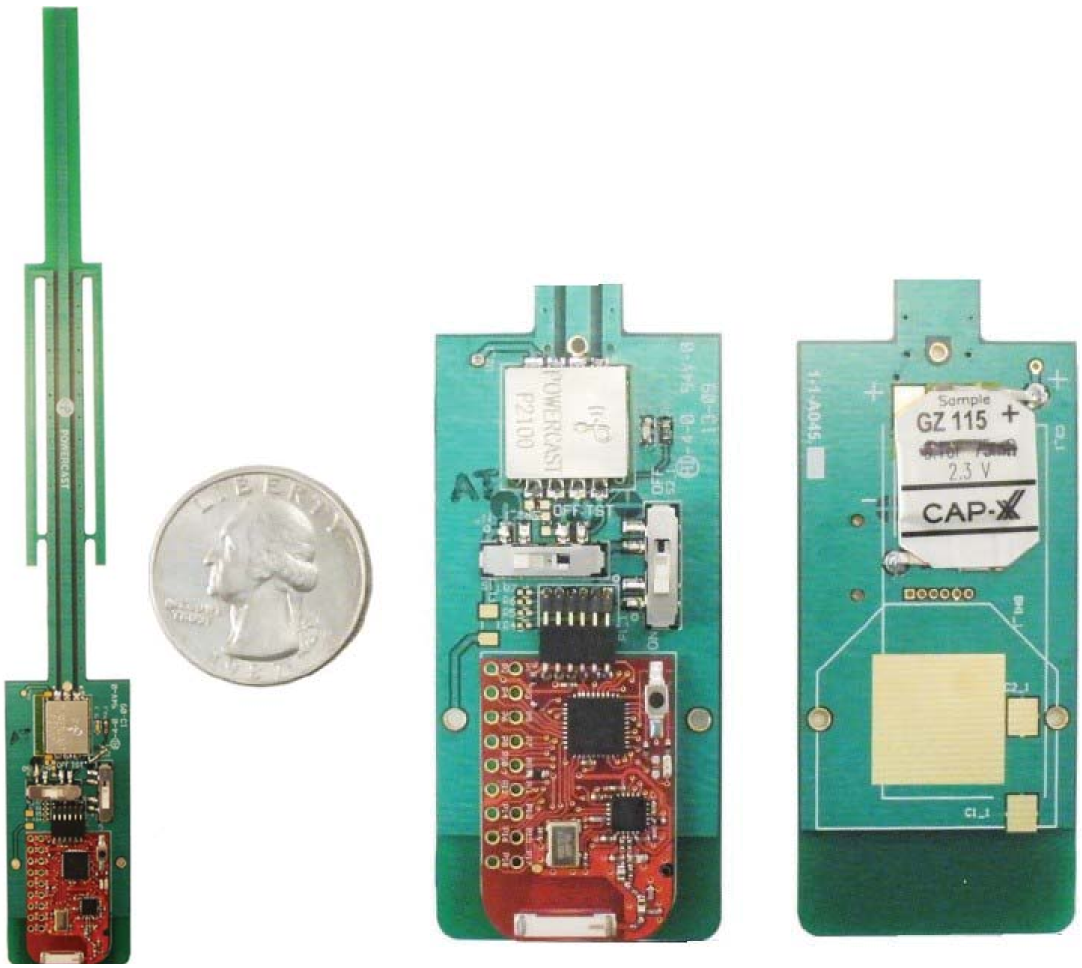


Figure 81: Powercast RF Energy Harvesting Module with Sleeve Dipole Antenna Powerharvester Module [73]

The critical difference between a supercapacitor and a standard capacitor is in the surface area supplied by the electrode and the thinness of the double layer formed at the electrode-electrolyte interface [57].

Where capacitors store energy in the electric field between a pair of oppositely charged conductors and have higher power density than batteries, they are able to charge and discharge over much shorter periods of time. However, their energy density is two to three orders of magnitude lower [57].

Although a battery-free system would mean lower maintenance, a battery would still likely need to be implemented and charged as there still needs to be continued research into capacitors in order to increase their energy density.

6.5.5. Further Investigation into Solar and Lead Acid Batteries

Solar cells are a technology which can play a key role in sensor node applications due to solar energy being a potentially limitless energy source. It is among the more feasible of the alternative energy harvesting options as promising results have already been achieved in the extraction of power from solar energy [74].

Lead acid batteries are one of the oldest rechargeable battery systems known for being quite economical in price, rugged, and forgiving if abused [63] in particular a high over charge tolerance [69].

The solar panel test showed that during an average day, a voltage output of 15.44V was attainable (Figure 82) allowing for adequate voltage supply to the lead acid battery which has a 13.6-13.8V trickle voltage charging value.

The silicon solar PV cell specifications are as follows:

- 254x294mm in dimensions
- Pm of 5W
- Vmp of 16.8V
- Imp of 0.30A

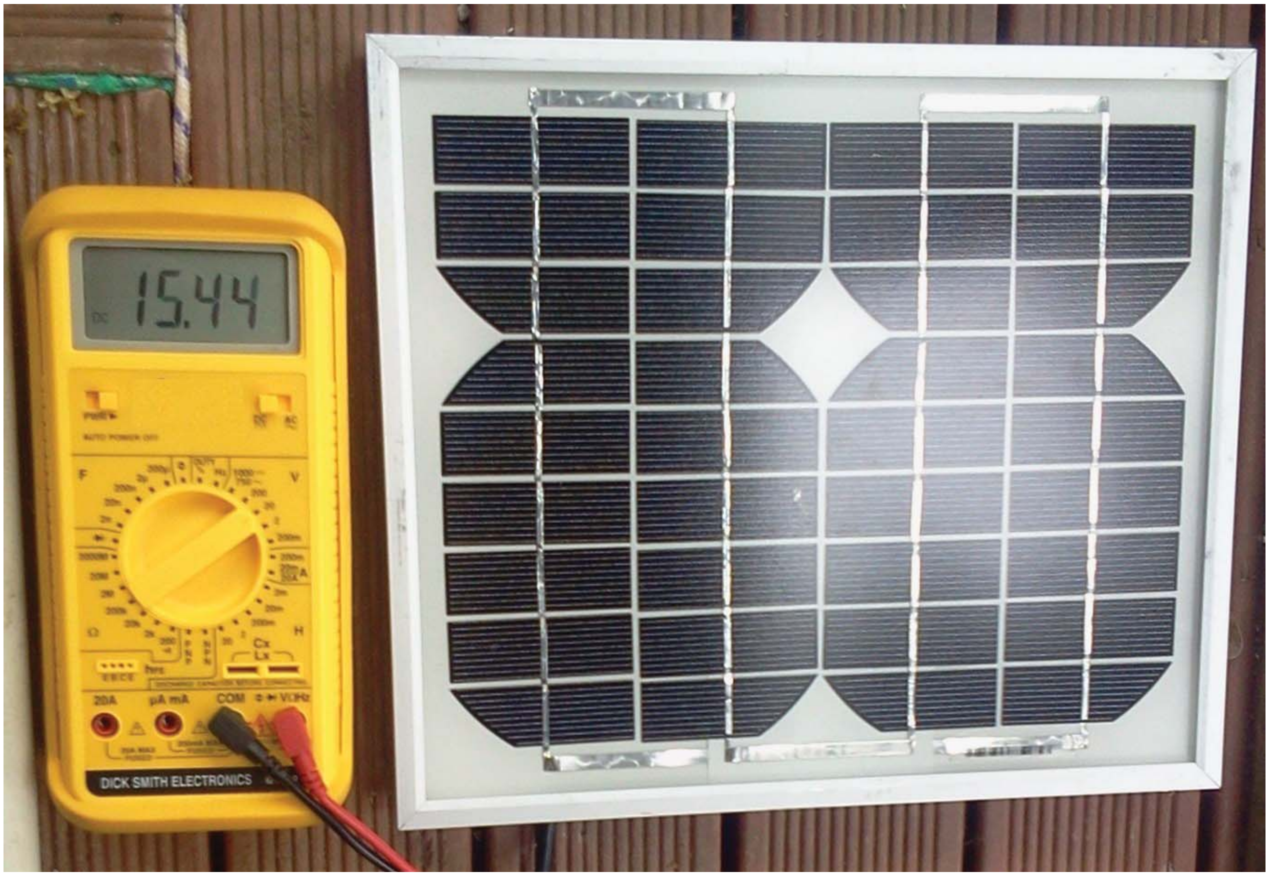


Figure 82: 15.44V Solar Reading on an Average Day

In order to limit the voltage output of the solar panel to the lead acid battery, the TL431 [75] was used where the output voltage can be set to any value between VREF 2.5V and 36V with two external resistors (6.5.1).

Where the TL431 is stated as having active output, it provides a very sharp turn-on characteristic making it an excellent replacement for Zener diodes in many applications. This is of particular interest where the TL431 has benefits over Zener diodes for power regulation with regards to precision and voltage drop.

$$V_{KA} = V_{REF} \times \left(1 + \frac{R_1}{R_2}\right) \quad (6.5.1)$$

$$V_{KA} = V_{OUT}$$

Where

$$V_{Ref} = 2.5V$$

$$V_{Out} = 13.7V$$

Calculation for External Resistors

R1=4.48R2

If assuming

R2=47K

R1=10.491K

Thus the selected values based on available resistor values are.

R1=10K

R2=47K

However, the use of the standard resistor values chosen gives a voltage output of 4.202V, as such an additional 1Kohm pot is used to adjust/ fine-tune voltage closer to the desired 13.7V (Figure 83).

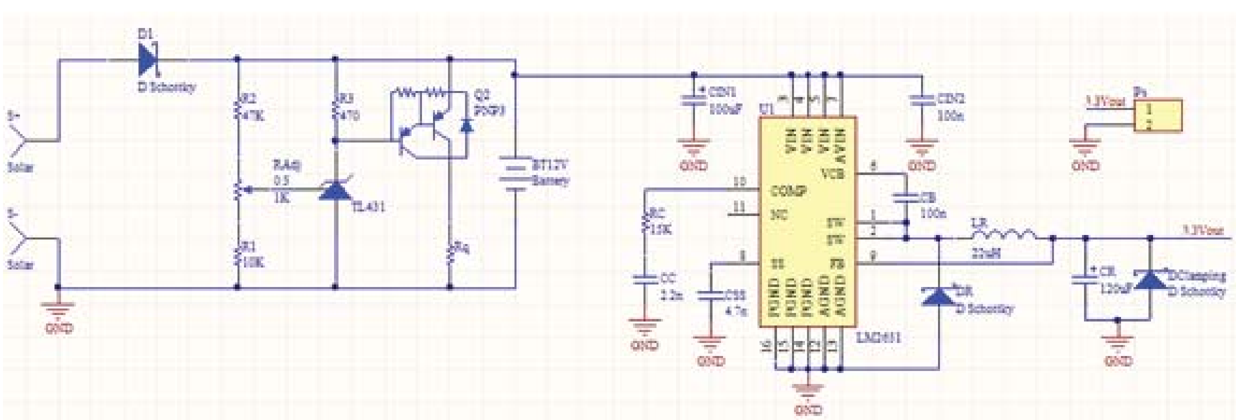


Figure 83: Schematic Design of Solar Power Regulator to Battery and 3.3V Regulator

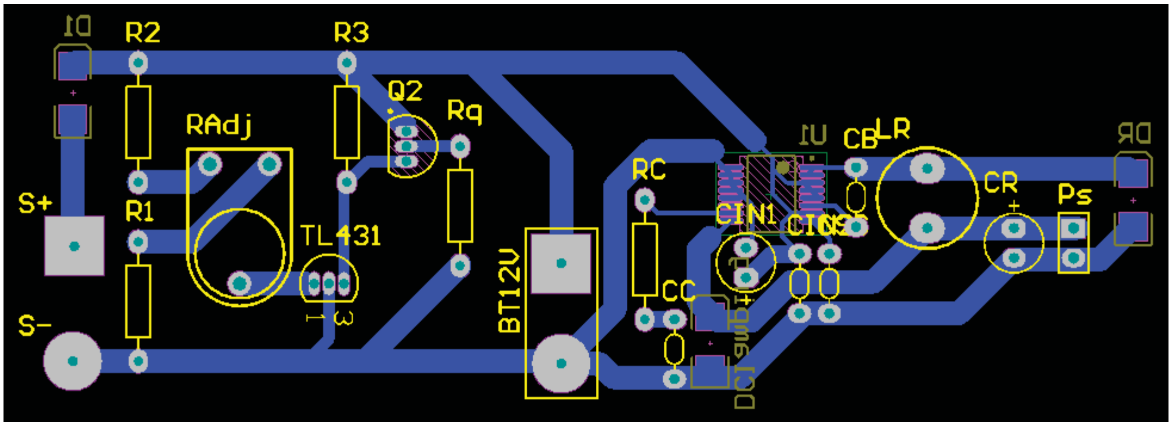


Figure 84: PCB Design of Solar Power Regulator to Battery and 3.3V Regulator

Testing of the solar output voltage limiting system was executed by using the TL431 configuration. A solar panel with a lamp to provide the light source (Figure 85) was used. The results of the Output Voltage limited to 13.7V with TL431 are shown (Figure 86).

Figure 85: Testing Procedure with Solar Panel and Lamp as Light Source

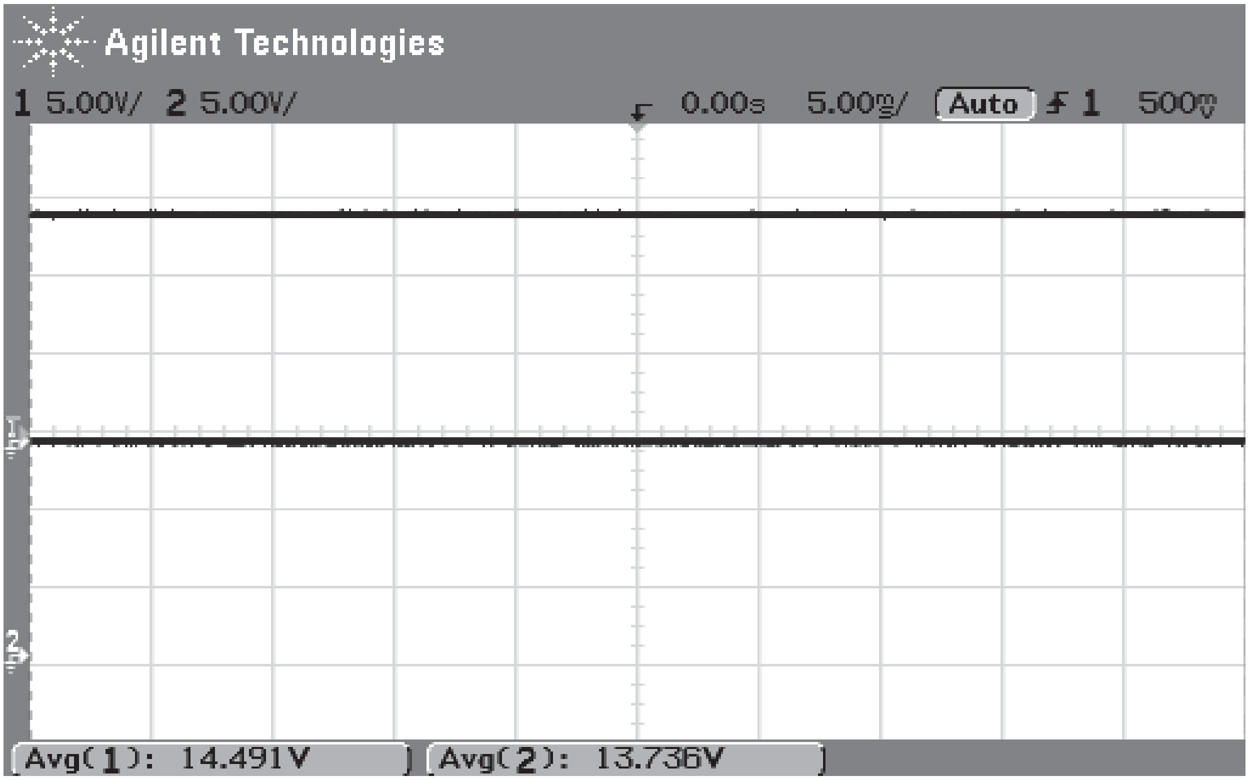


Figure 86: Oscilloscope Reading for Circuit from Solar Panel where Output Voltage Limited to 13.7V with TL431

The investigation was performed in order to provide a 3.3V output voltage from the battery and solar system using a LM2651 1.5A High Efficiency Synchronous Switching Regulator [76].

Key Features:

- Ultra high efficiency (Figure 87) up to 97%
- High efficiency over a 1.5A to milliamperes load range
- 4V to 14V input voltage range
- Output voltage of 3.3V

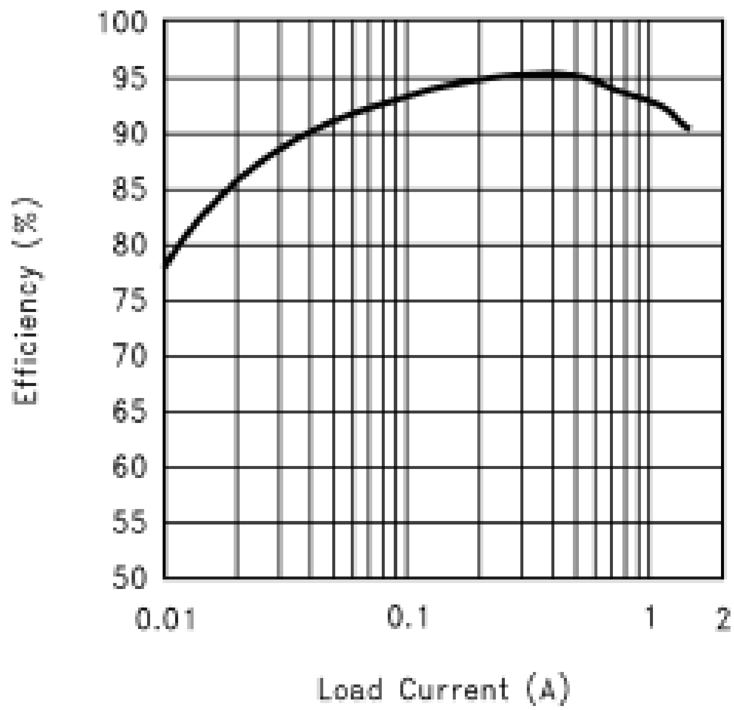


Figure 87: Efficiency vs. Load Current LM2651 [76]

The LM2651 operates in a constant frequency (300 kHz), current-mode PWM for moderate to heavy loads, and it automatically switches to hysteretic mode for light loads.

6.5.6. Evaluation

The current work allows for charging of a lead acid battery with solar power should it perform adequately. The investigated system limits the voltage output from solar panel to lead acid battery in order to allow for its safe charging at 13.7V. The work done is a basic solar harvesting implementation. Further exploration can be done in order to further optimise the efficiency of the solar harvester and battery charging. This may require the system to incorporate intelligent electronics systems for monitoring, in which case further work should be done in weighing up the benefits of utilising commercial offerings of plug-and-play solar energy harvesting modules.

6.6. MEASUREMENT FOR RF SIGNAL STRENGTH

6.6.1. Introduction Receive Signal Strength Indicator (RSSI)

The IEEE 802.11 standard defines a mechanism by which RF energy can be measured by the circuitry on a wireless NIC [14]. This numeric value is a number called the Receive Signal Strength Indicator (RSSI) where each vendor's 802.11 NIC will have its own specific configuration for RSSI value. The IEEE 802.11 [47] standard discusses the RSSI metric within, stating that: "The receive signal strength indicator (RSSI) is an optional parameter and that the parameter is a measure by the PHY sub-layer of the energy observed at the antenna."

Although absolute accuracy of the RSSI reading is not specified and the parameter optional, most 802.11 radio modules support Received Signal Strength Indicator (RSSI), which means, it is possible to obtain received power for each received packet [77] even though there is no specified accuracy to the RSSI reading. There is nothing in the 802.11standard that stipulates a relationship between RSSI value and any particular energy level as would be measured in mW or dBm[78]. However, vendors like RFM who is the vendor for the WSN802G have specified and provide their calculation and values for power in the RSSI value in dBm.

Additionally in the practical application of wireless sensor networks (WSN)[79] sensor node localization is desirable for implementation in sensor networks. In particular a localization system based on RSSI (Received Signal Strength Indicator) is able to employ localization methods based on displacement/ distance measurement.

6.6.2. RSSI and Distance Measurements

Tests were performed to check the relationship between RSSI transmitted by the WSN802G module and the displacement/ distance of the module with regards to the access point or router. The results of this test are shown in Figure 88. Tests were performed by placing the WSN802G sensor nodes at different distances and logging the transmitted RSSI values. Each test was performed with a clear line of sight and lasted 15mins in order to give a good sample averaging.

The trend of RSSI with distances can be seen as a non linear relationship and would be better fitted to a curve as shown in (Figure 88), where the RSSI unit is dbm and the distance unit is meters.

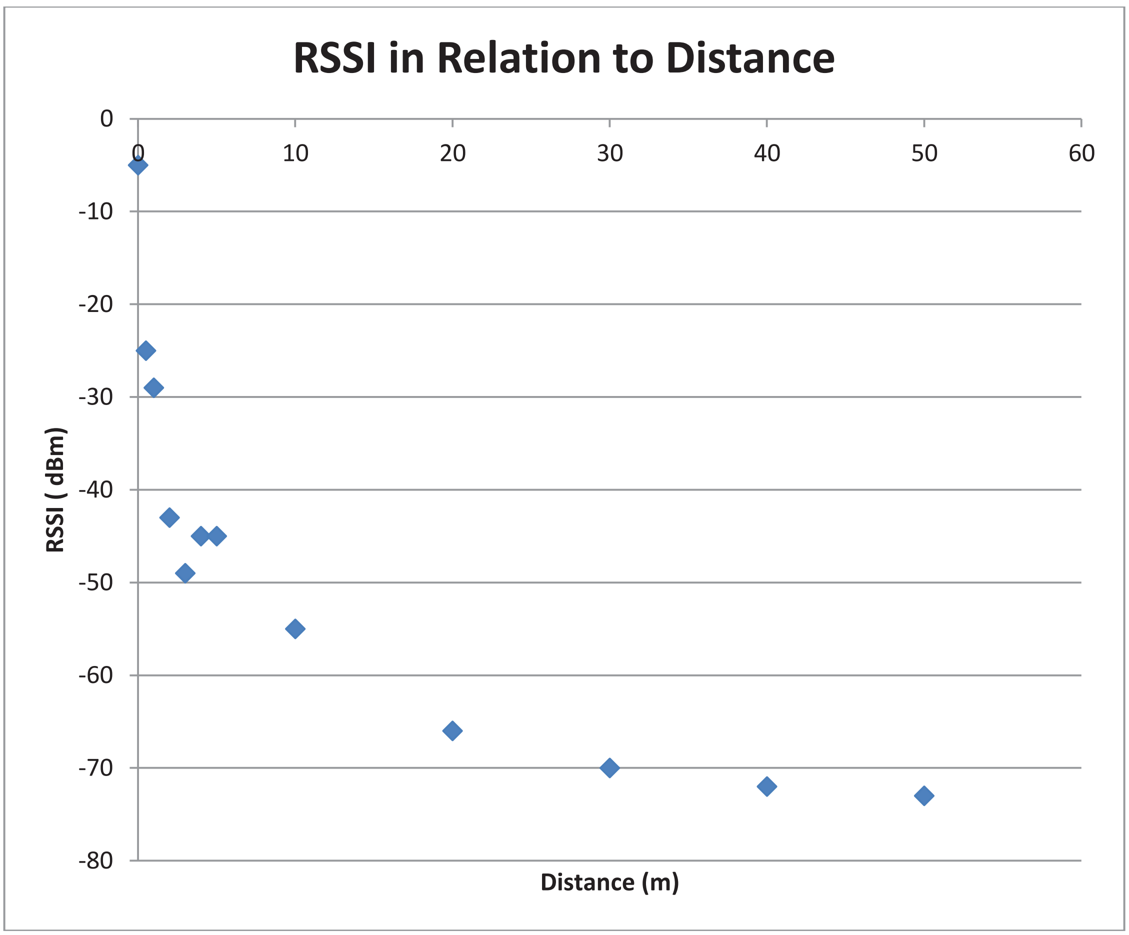


Figure 88: The Relationship between Distance and Logged RSSI Values

6.6.2.1. RSSI and Distance in Fruit Orchard

Similar tests were performed in a different environment such as a fruit orchard (Figure 89) to further check the relationship between RSSI transmitted by the WSN802G module and the displacement/ distance of the module with regards to the access point or router. The results and comparison of this test and the previous test are shown in (Figure 90). Tests were performed by placing the router in the middle of a fruit orchard (Figure 89) and WSN802G Sensor nodes at different distance where the transmitted RSSI values were logged. Again, each test lasted 15mins in order to give a good sample for averaging.

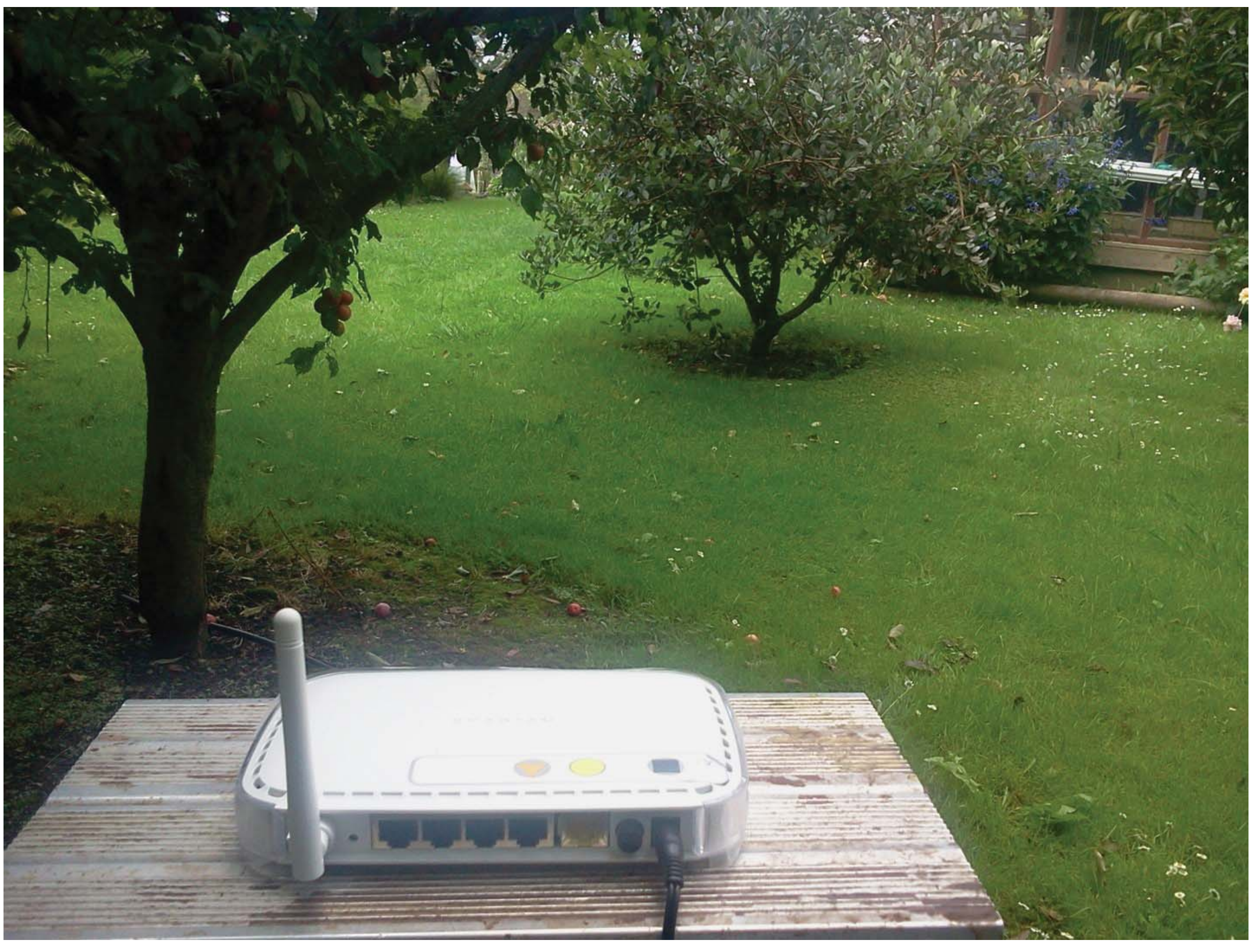


Figure 89: Layout of the Test in a Fruit Orchard

The plotted results (Figure 90) show that RSSI values match up at closer distances. However at further distances past obstructions such as fruit trees, RSSI with relation to distance values vary more significantly especially the further away the module gets from the router.

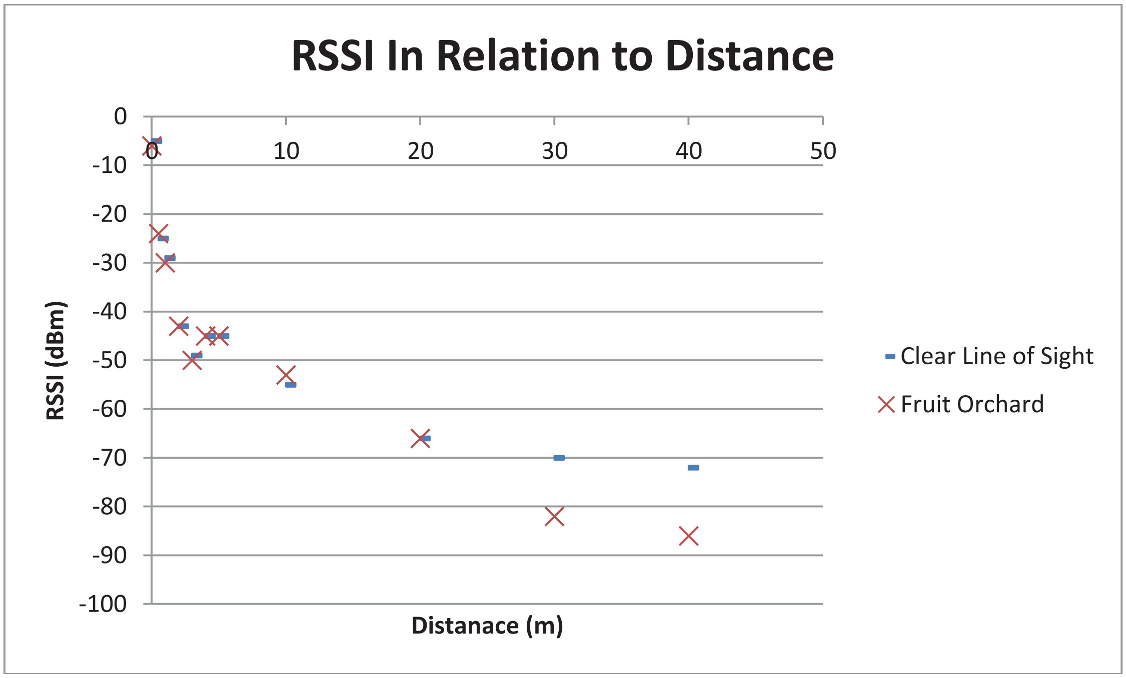
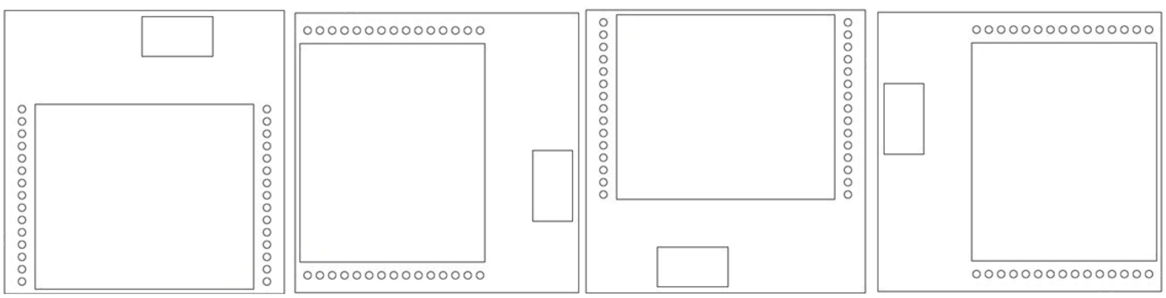


Figure 90: The Relationship between Distance and Logged RSSI Values

6.6.2.2. RSSI, Distance and Module Orientation

Further testing was done to view effect of the relative orientation of the WSN802G modules on experimental results. Testing was performed where the orientation angles between WSN802G modules and Router were varied as shown in (Figure 91). The results from these tests are shown in (Figure 92).



0 Degrees | 90 Degree | 180 Degrees | 270 Degrees

Figure 91: Orientation of WSN802G Module with Respect to Router

The resulting plot of RSSI values measured over 5 meters in (Figure 92) shows the WSN802G module at different orientations. There appears to be certain closer distances at which the orientations between router and module have a greater effect on RSSI value in particular with 180° rotation. It appears that at further distances the RSSI values converge, meaning that at further distances orientation will likely have less of an effect on the values.

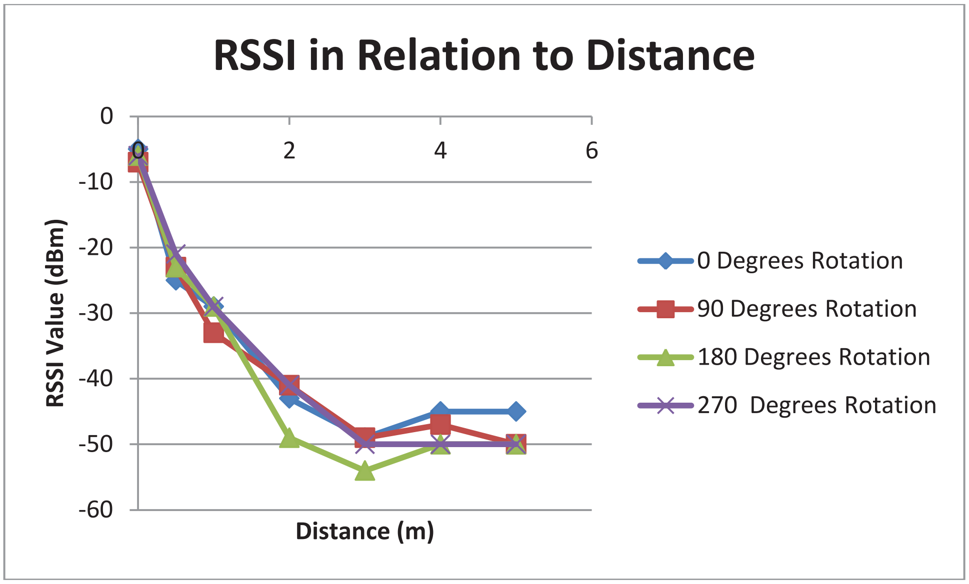


Figure 92: RSSI value and Distance in Conjunction with Orientation

6.6.3. Evaluation

There is some definite relationship between RSSI value and distance which allows for further investigation on a RSSI-based distance measure for use in the wireless sensor network.

Future implementation of a RSSI-based distance measure is possible where it could allow for a low-power, low-cost method. It also has the obvious advantage of allowing for use of information readily available and already implemented. Though the RSSI-based method can be influenced by environment, reflection, orientation and interference, it could still provide adequate results for distance measurement and localization in an outdoor environment. Therefore the RSSI-based method could be of further interest for investigation and could be used together with other methods and models such as propagation models [77][80] for more accurate distance estimation.

7) FINAL SENSOR NODE CONFIGURATION AND EXPERIMENTAL RESULTS

7.1. SYSTEM OVERVIEW

An agricultural climate is a complex system. It consists of many environmental factors that affect the development of agricultural products. Some of these environment factors are interconnected and they should be considered together while others can be considered individually. Therefore, it was essential to know which environmental factors affect one another in order to have sensor outputs configured correctly. One such example is where humidity values are related to temperature.

The system being developed is based around the WSN802G Wi-Fi / 802.11 modules in order to communicate data to a selected Server (Figure 93). Further details follow on how the WSN802G module is connected to the various sensors with analogue outputs.

7.1.1. The Sensor Node

An important aspect of the design was its compact size where the WSN802G module was used as the key element of the sensor node. The sensor node consists of the following:

- ADC Protection
- Multiplexer
- Counter
- WSN802G module
- Sensors

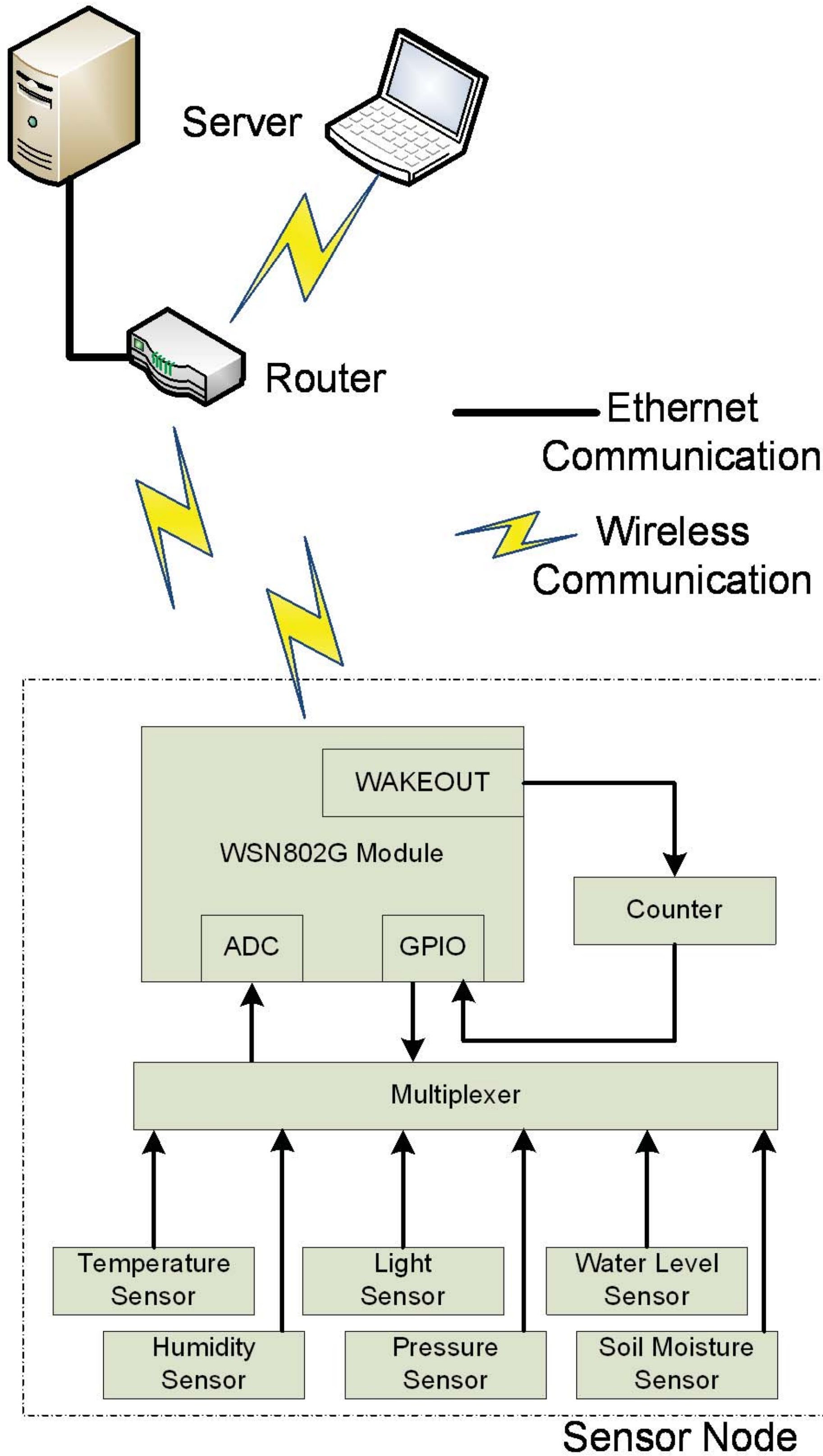


Figure 93: Functional Block Diagram of System being Developed

7.2. ADC PROTECTION

The WSN802G module and its ADCs have the maximum voltage range that the system utilizes. The WSN802G module is of crucial importance for the functioning of WSN. It was important to have good ADC protection so that the output of the sensors used should remain within the required range. A TLV431 three terminal adjustable shunt regulator was used to restrict the voltage output as a precaution

The TLV431 is a three terminal adjustable shunt regulator offering excellent temperature stability [81] which is of great importance as environmental temperature range may vary considerably. Using the TLV431 the output voltage may be set to any chosen voltage between 1.24 and 18 volts by selection of two external divider resistors (Figure 94). The ADC Protection circuitry is used to make sure that inputs to the ADC's do not exceed the recommended 1.8/1.9V where the values of R1 and R2 determine the value for output voltage (7.2.1).

$$V_{OUT} = V_{REF}\left(1 + \frac{R1}{R2}\right) \quad (7.2.1)$$

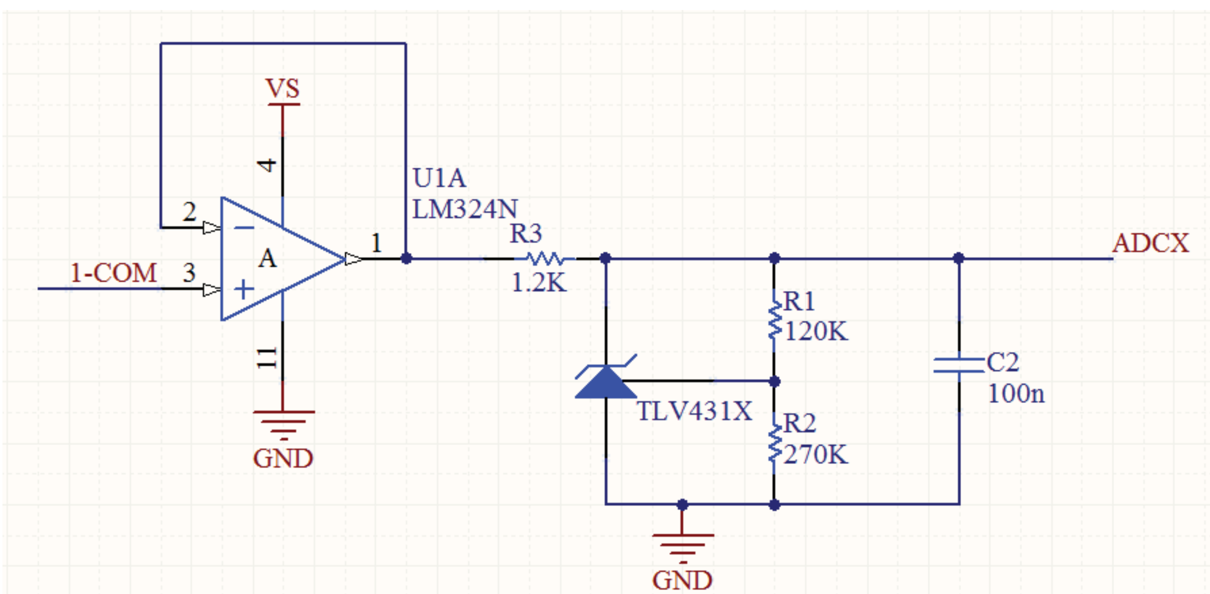


Figure 94: ADC Protection limiting to 1.8V

The system has the TLV431 configured to limit Vout to a maximum of 1.8V so as to be within the WSN802G ADC voltage range. The ADC protection configuration suitably limits the maximum voltage output, while maintaining a suitable linear voltage for the other values that are within the acceptable range (Figure 95).

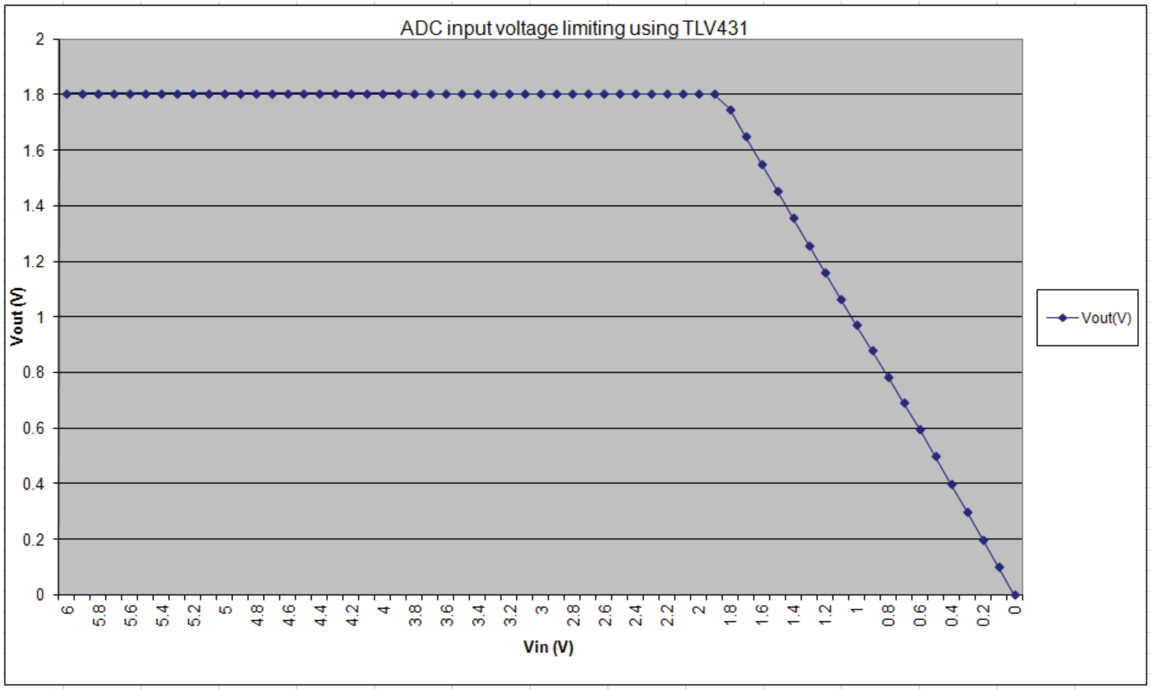


Figure 95: Plot of Vinput Voltages against Output Voltages for TLV431

7.3. MULTIPLEXER

The WSN802G module is connected to the various sensors with analogue outputs via a multiplexer used for signal gating. The Multiplexer used was the SN74LV4052A Dual 4-Channel Analogue Multiplexer [82]. It is a 16 pin device that has a supply voltage range: 2V to 5.5V

FUNCTION TABLE

INPUTS			ON CHANNEL
INH	B	A	
L	L	L	1Y0, 2Y0
L	L	H	1Y1, 2Y1
L	H	L	1Y2, 2Y2
L	H	H	1Y3, 2Y3
H	X	X	None

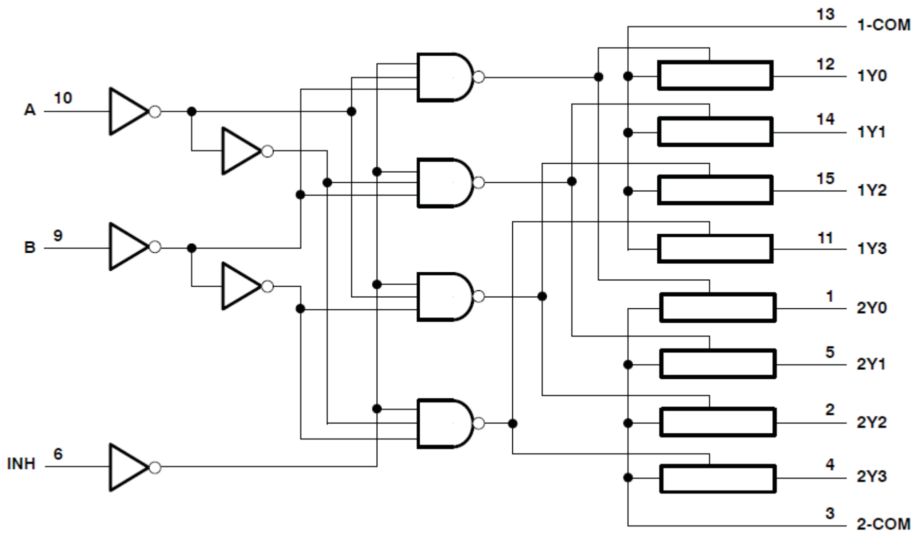


Figure 96: Multiplexer Logic Diagram [82]

The multiplexer or mux allows for the selection of one of several input signals and forwards the selected input into a single line. Thus it is possible for several signals to share one A/D converter instead of having one device per input signal. The multiplexer channels can be selected based on inputted values for A and B (Figure 96).

As stated previously the WSN802G module and its ADCs are connected to the various sensors with analogue outputs via a multiplexer used for signal gating. The various sensors are connected to different channels of the multiplexer where considerations were made to keep data transmission of temperature and humidity together, as humidity values are related to temperature.

Additionally the two ADCs; ADCX and ADCY of the WSN802G module are connected to the multiplexer's 1-COM and 2-COM ports respectively.

The WSN802G has General Purpose Input/Output (GPIO) pins where the system uses values inputted for the GPIO0 and GPIO1 select multiplexer channels connected to the ADC at specific times (Figure 97). The values inputted to GPIO and GPIO1 can either be based on the counter output which is talked about in the following section or can be based entirely on the other GPIO output values on the WSN802G module (Figure 98). Values inputted to GPIO and GPIO1 are transmitted and logged in order to notify which set of sensors are being monitored at a given time.

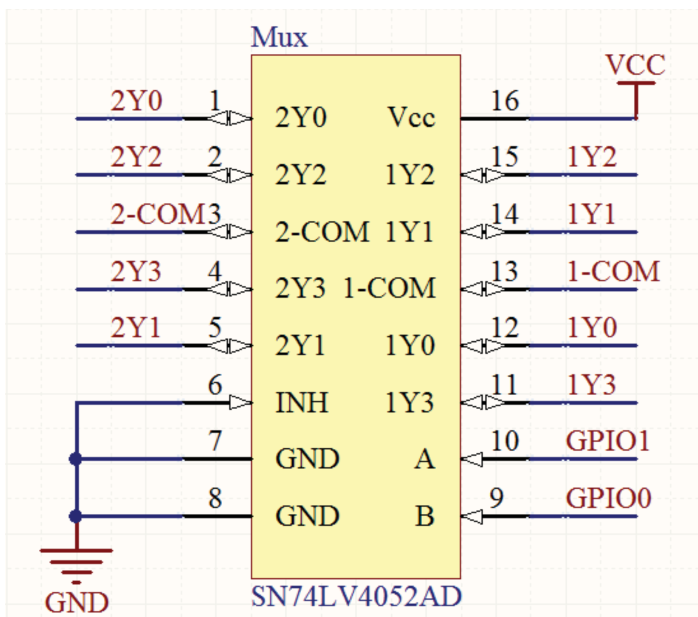


Figure 97: Multiplexer Pin Configuration

If the option is selected and in order for multiplexer channel selection to be based entirely on the GPIO values from the WSN802G, the WSNConfig application (Figure 98) allows for selection of GPIO values to the multiplexer.

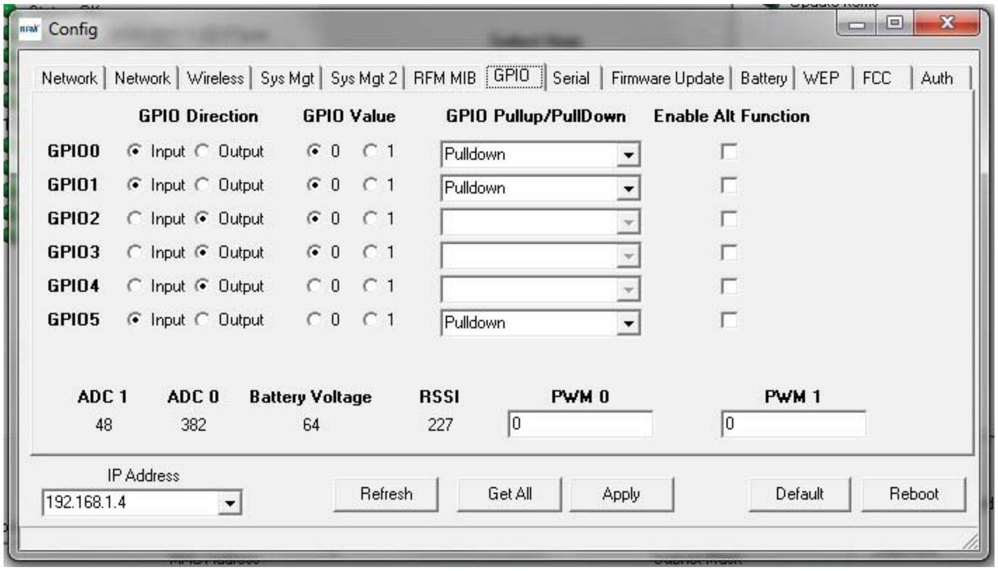


Figure 98: GPIO Selection via WSNConfig

7.4. COUNTER FOR SWITCHING

Although the multiplexer channels can be selected entirely by the WSN802G module this can be inefficient at times and requires user interaction. The 74HC4040 are 12-stage binary ripple counters utilised to address this issue. The 74HC4040 is a high-speed Si-gate CMOS device with a clock input (CP), an overriding asynchronous master reset input (MR) and twelve parallel outputs (Q0 to Q11) [83].

INPUTS		OUTPUTS
$\overline{CP}$	MR	Q_n
↑	L	no change
↓	L	count
X	H	L

Notes

1. H = HIGH voltage level
   L = LOW voltage level
   X = don't care
   ↑ = LOW-to-HIGH clock transition
   ↓ = HIGH-to-LOW clock transition

Figure 99: Counter Transition Functions [83]

Each counter stage is a static toggle flip-flop and the counter advances on the HIGH-to-LOW transition of CP (Figure 99). The system uses the WSN802G Wakeout output (Figure 100) from the WSN802G in order to have the counter output transitions occur.

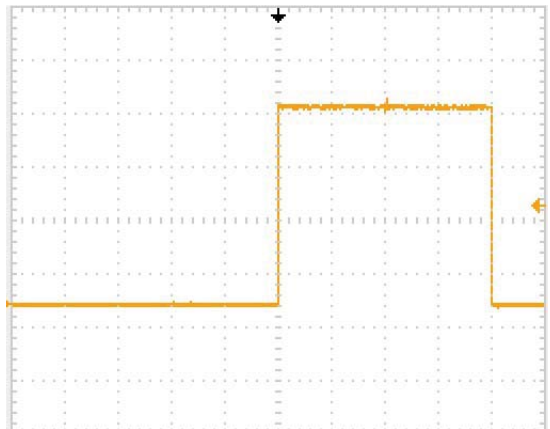


Figure 100: Wakeout Output from WSN802G

The occurrence of Wakeout output from the WSN802G module is configurable via the WSNConfig application (Figure 101) where the Values of "Wake Out Post delay" and "Wake Out Predelay" set the occurrence and length of Wakeout output from WSN802G module.

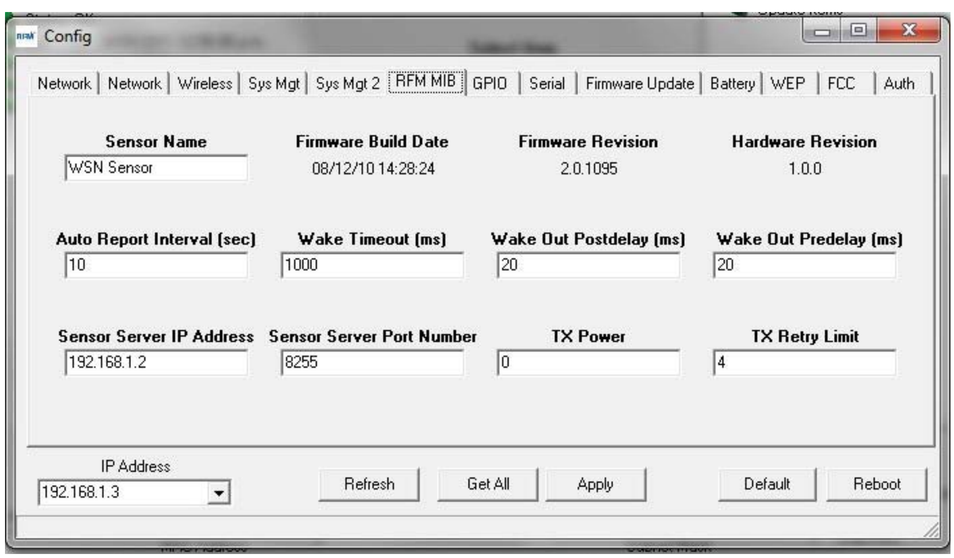


Figure 101: WSNConfig Control for Wakeout Occurrence

When the counter is selected for automatic sensor switching, the counter output Q0 is used by multiplexer input B/GPIO0 and Q1 is used by multiplexer input A/GPIO1. Unused counter outputs were left open as per counter specification. This allows multiplexer channels to be selected based on the counter output and allows for automatic sensor switching with no required user interaction. The counter being used for switching sensor outputs to WSN802G ADCs can be seen in the WSNDemo Program that is used for logging of transmitted data (Figure 102).

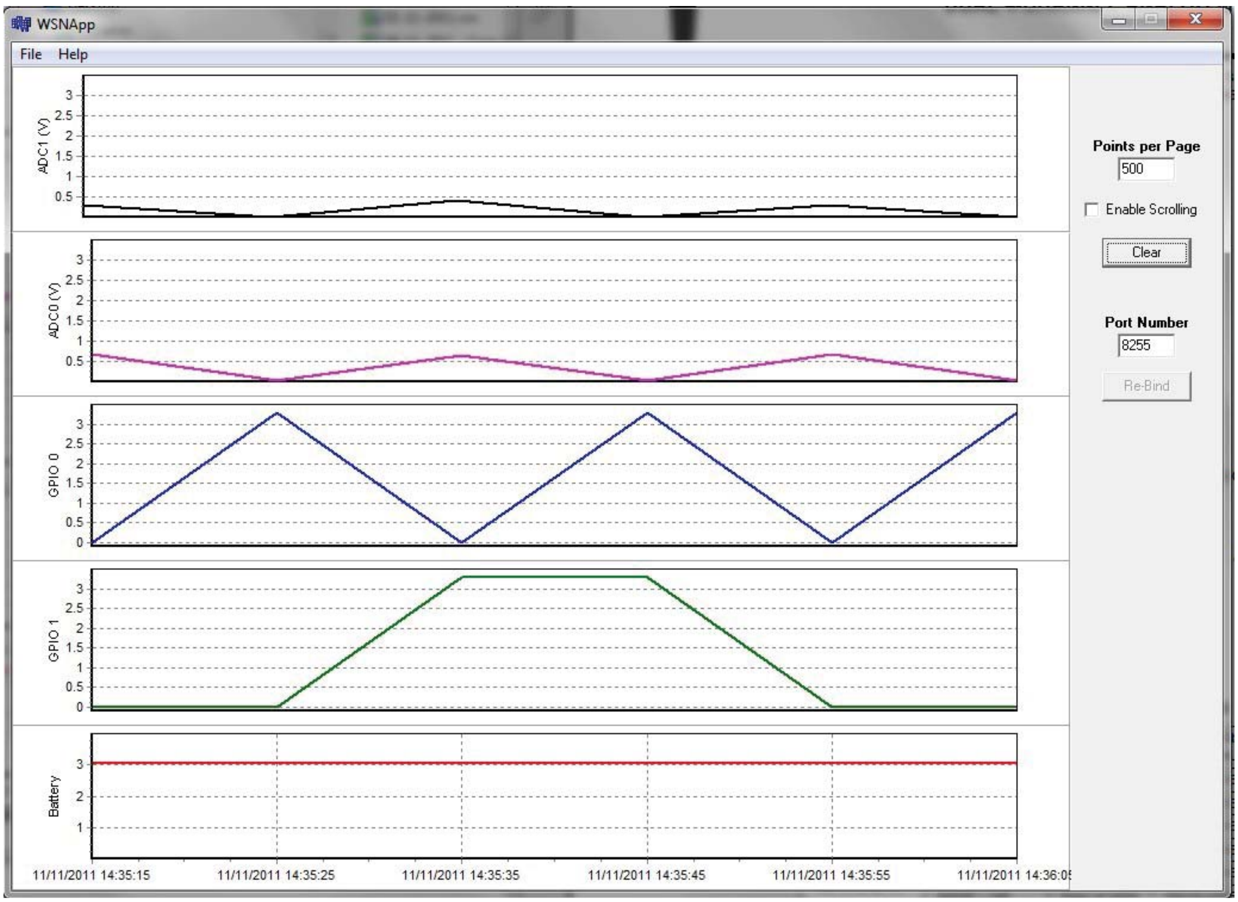


Figure 102: Counter Switching used to Change Sensors Outputs to WSN802G ADCs

7.5. HARDWARE DESIGN OF THE SENSOR UNIT

The sensor station consists of a single sensing unit: that contains ADC protection, a multiplexer, counter, WSN802G module and sensors. The design of sensor unit was done in the Altium Designer software package.

The sensing unit consists of the following sensor:

- D600 [27] temperature sensor
- HIH-4010 [28] Humidity sensor
- ADPS-9002 [29] ambient light photo sensor
- NPP-301[30] NovaSensor Pressure Sensor
- 2 x VG400-LV [31] low frequency sensor for soil moisture and water level measurement

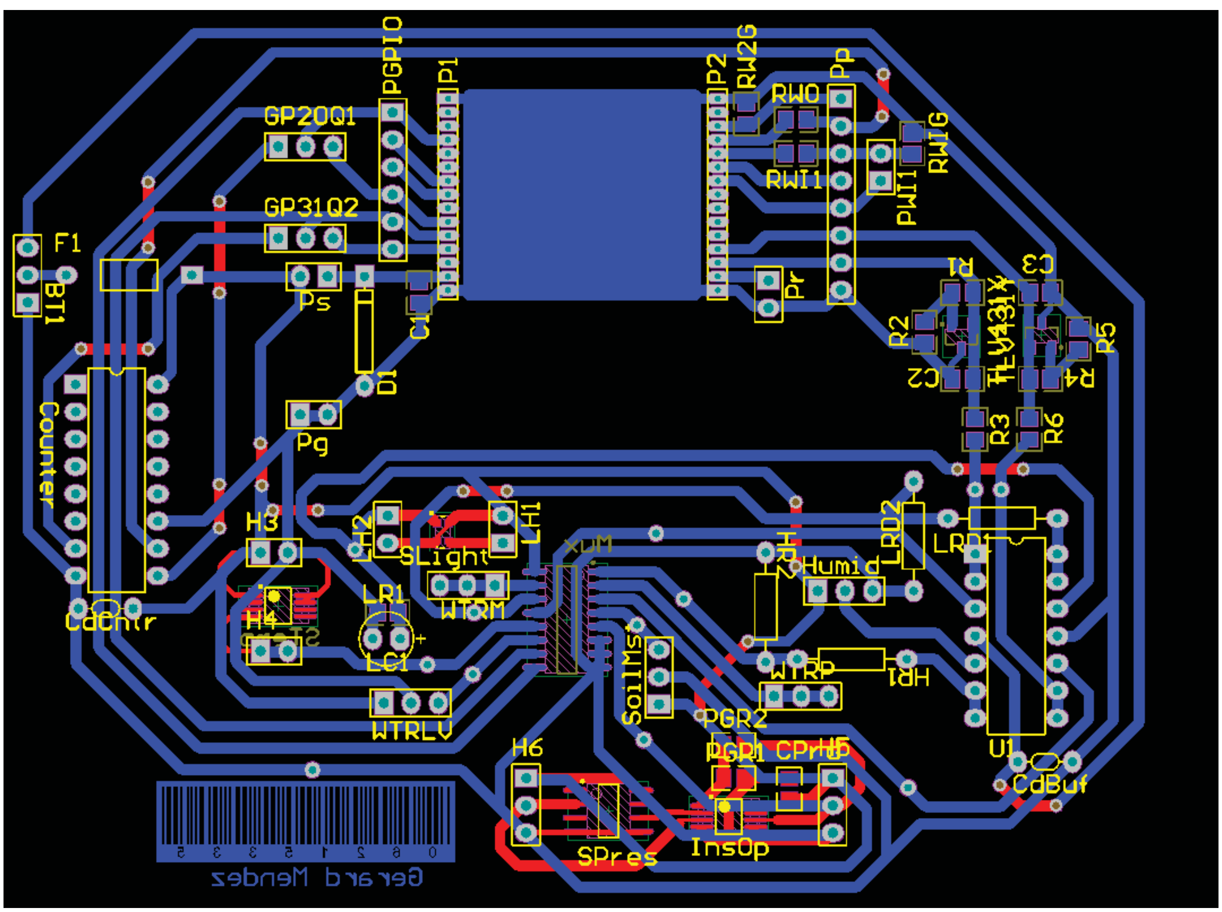


Figure 103: PCB Design of the Sending Nodes

An important aspect of the design was keeping the size of the node compact. Therefore a large proportion of circuitry components used are either surface-mounted or are very small in size. The final design of the sensor node (Figure 104) includes the circuitry for automatic sensor switching. The sensing node is shown below (Figure 104).

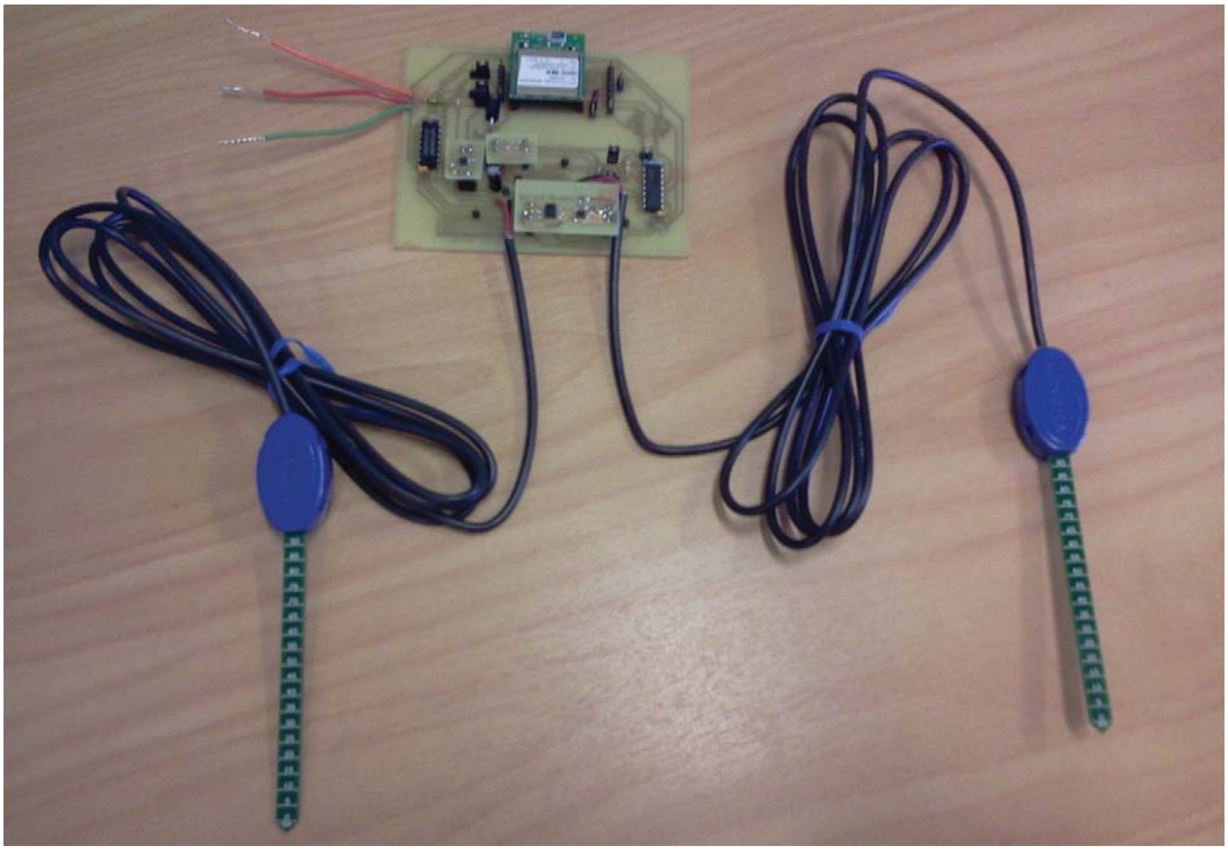


Figure 104: Final Design of the Sensor Station

7.6. DEPLOYMENT OF SYSTEM

The developed systems were utilized in various locations such as lab, hydroponic greenhouse and a backyard. The results for sensor output displayed in previous sections were acquired from deployment of system in a Hydroponics green house (Figure 105) that was previously being used to grow tomatoes, snow peas and lettuce. The system was deployed for days at a time attached to a power supply that was readily available in the

Hydroponics green house. The system performed as expected with good reliable transmissions where the module was 45meters away from the access point.

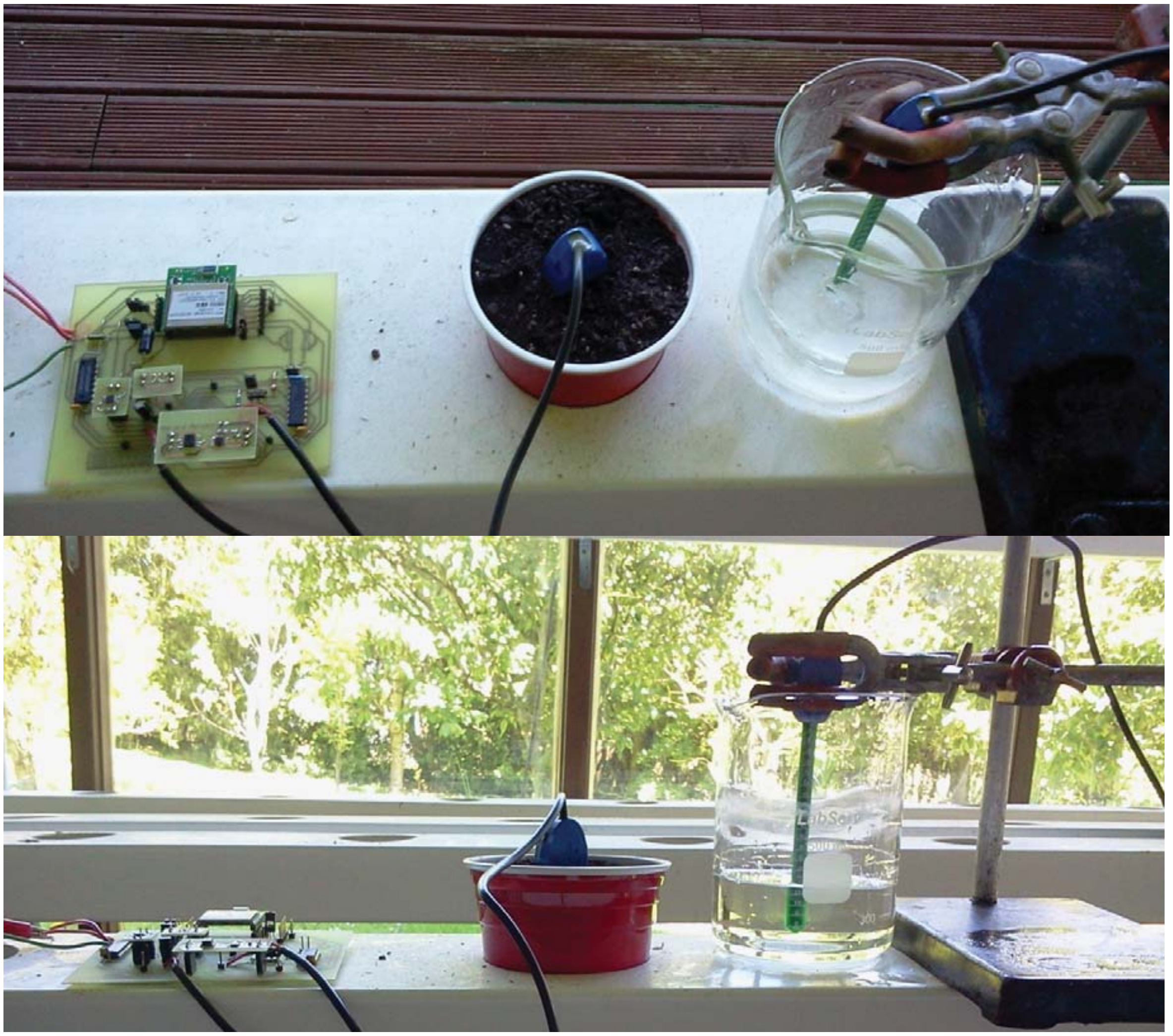


Figure 105: Test Conditions in Hydroponics Greenhouse

7.7. DATALOGGING

Based upon the source code for a graphing application called WSNApp, provided by RFM, a logging program was created. This logging application was written in the Embarcadero C++ Builder development environment (Figure 106).

C++ builder is designed for ultra-fast, component-based creation of highly-maintainable, visually stunning GUI applications, yet it is still able to code in ANSI/ISO compatible C++.[84] This allows for the power of C++ for embedded system in conjunction with the productivity of other more visual inclined development environments. The configuration application WSNConfig can be run separately or at the same time as the written logging application program WSNDemo, allowing for WSN802G module configuration support while logging.

This is possible as the WSNConfig.exe configuration commands run on Port 161, and WSNConfig.exe listens for SNMP commands on Port 162 [52] where as the written WSNDemo sensor server application runs on Port 8255.

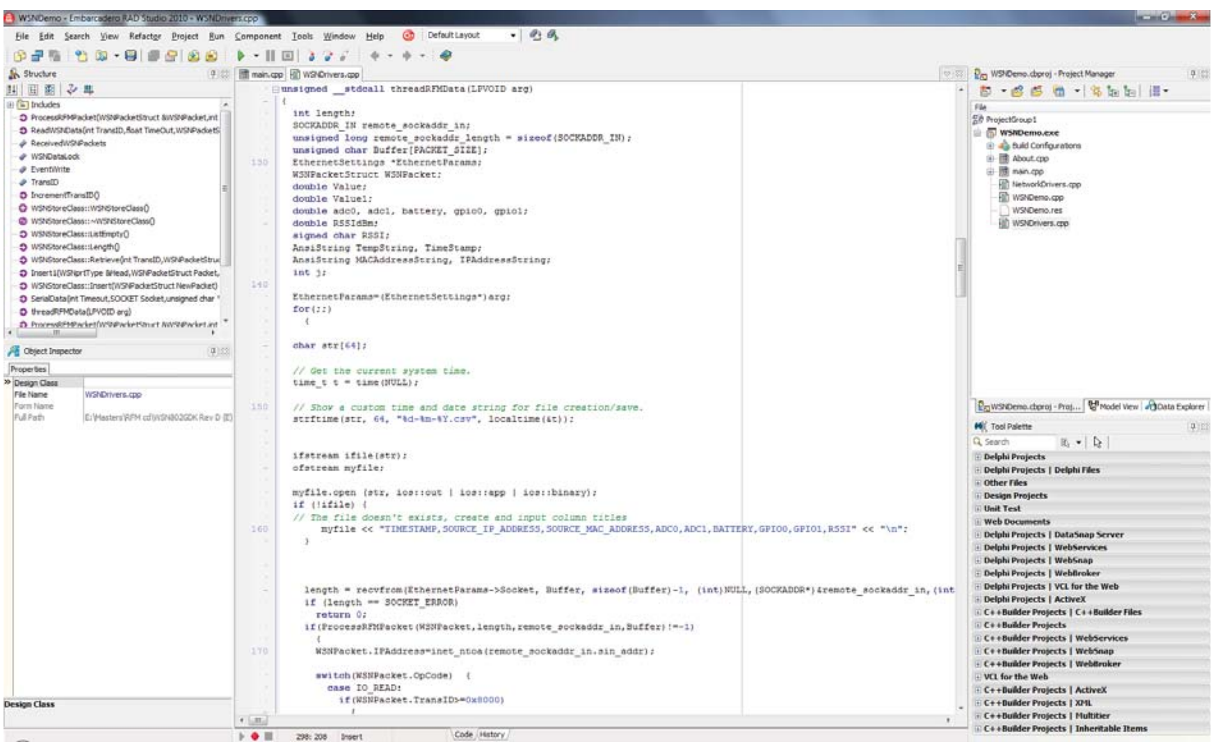


Figure 106: Embarcadero C++ Builder Development Environment

7.8. C++ BUILDER CODE FOR CSV FILE

The written appplication WSNDemo is based on the source code of a graphing application called WSNApp provided by RFM. This logging application written in the

Embarcadero C++ Builder development environment creates a CSV FIle with the code in (Figure 107).

```
char str[64];

// Get the current system time.
time_t t = time(NULL);

// Show a custom time and date string for file creation/save.
strftime(str, 64, "%d-%m-%Y.csv", localtime(&t));


ifstream ifile(str);
ofstream myfile;

myfile.open (str, ios::out | ios::app | ios::binary);
if (!ifile) {
// The file doesn't exists, create and input column titles
    myfile << "TIMESTAMP,SOURCE_IP_ADDRESS,SOURCE_MAC_ADDRESS,ADC0,ADC1,BATTERY,GPIO0,GPIO1,RSSI" << "\n";
  }
```

Figure 107: Code for CSV File Creation

When the modified WSNDemo application is run, it creates a CSV file in the same directory as the WSNDemo application being executed. The CSV file with a filename of the current date is created in the form of “DD-MM-YYYY.csv”, for example a new log file created for the 20th of September 2011 would be "20-09-2011.csv". In addition when the file is created it adds input column titles. If a file already exists for logging of data for that date it will carry on adding entries to that file.

The code "ios::out" opens the file for output operations, "ios::binary" opens the file in binary mode and "ios::app" sets all the output operations to be performed at the end of the file, appending the content to the current content of the file. This flag is usable in streams open for output-only operations as indicated previously.

The data logged per I/O Report entry is Timestamp, Source IP Address, Source MAC Address, ADC0 value, ADC1 value, Battery/Supply Voltage, GPIO0 and GPIO1 values and RSSI (Figure 58).

```
        //MAC Address to string
         MACAddressString="";
           for (j=0;j<6;j++)
             {
             // Using IntToHex function
             MACAddressString+=IntToHex(WSNPacket.MACAddress[j],2);
             if (j<5)
             // Inserting ":" character between MAC Address values
               MACAddressString+=":";
             }


          //IP Address
          IPAddressString= WSNPacket.IPAddress;


          //Timestamp in format dd/mm/yyyy hh:nn:ss
          TimeString = FormatDateTime("dd/mm/yyyy hh:nn:ss", Now()).c_str();


          // ADC0
          Value=(WSNPacket.Payload[0]<<8);            //Shift left 8 bits
          //Add remaining bits to value
          Value+=(WSNPacket.Payload[1]);
          Value*=(ADC_REF/ADCVALUE);
          adc0=Value;


          // ADC1
          Value=(WSNPacket.Payload[2]<<8);            //Shift left 8 bits
          //Add remaining bits to value
          Value+=(WSNPacket.Payload[3]);
          Value*=(ADC_REF/ADCVALUE);
          adc1=Value;
```

Figure 108: Code for Retrieving Data from WSNPacket for Addresses and ADCs as well as Timestamp Formatting

(Figure 108) indicates code for retrieving data from a module's transmitted packet for MAC address and IP address. MAC address uses the IntToHex function in order to get hexadecimal equivalent in order to better store value in the standard "00:30:66:00:03:72" format Timestamp formatted as dd/mm/yyyy hh:nn:ss. Additionally the ADC calculations are carried out in order to convert values into voltage units.

- ADC_REF is equal to 1.8V
- ADCVALUE = 2^{10} = 1023 as WSN802G uses 10-bit ADCs

```
// Battery
Value=(WSNPacket.Payload[4]<<8);            //Shift left 8 bits
//Add remaining bits to value
Value+=(WSNPacket.Payload[5]);
Value/=1000;
battery=Value;


// GPIO0 with bitwise AND operatoion with GPIO0 mask
Value=(WSNPacket.Payload[9]&GPIO0);
Value*=MAX_VOLTAGE;
gpio0=Value;


// GPIO1 with bitwise AND operator with GPIO1 mask Shift 1bit right
Value=((WSNPacket.Payload[9]&GPIO1)>>1);
Value*=MAX_VOLTAGE;
gpio1=Value;


//RSSI
RSSI=(WSNPacket.Payload[7]);
     ~RSSI;                               //two's complement
     RSSI++;
     RSSIdBm =RSSI;
     RSSIdBm -=2;


 //File write then close
     myfile <<TimeString.c_str()<< "," << IPAddressString.c_str() << ","
       << MACAddressString.c_str() << "," << adc0 << "," << adc1 << ","
       << battery << "," << gpio0 << "," << gpio1 << "," << RSSIdBm <<"\n";

     myfile.close();
```

Figure 109: Code for Retrieving Data from WSNPacket for Battery, GPIOs and RSSI Values as well as Writing the Data to a File

(Figure 109) indicates the code for retrieving data from a module's transmitted packet for battery voltage, GPIOs and RSSI along with the code for writing the data to the CSV file.

Additionally the GPIO calculations are carried out in order to convert values into voltage units where MAX_VOLTAGE is equal to 3.3V. The raw data for RSSI value is in the 2's complement of the RSSI in dBm and only the lower one-byte value is of interest.

As part of the Write File Command, the output operations on a file is closed so that it may become available again and opened later. This is done with the stream's member function `close()`. This function flushes the associated buffers and closes the file.

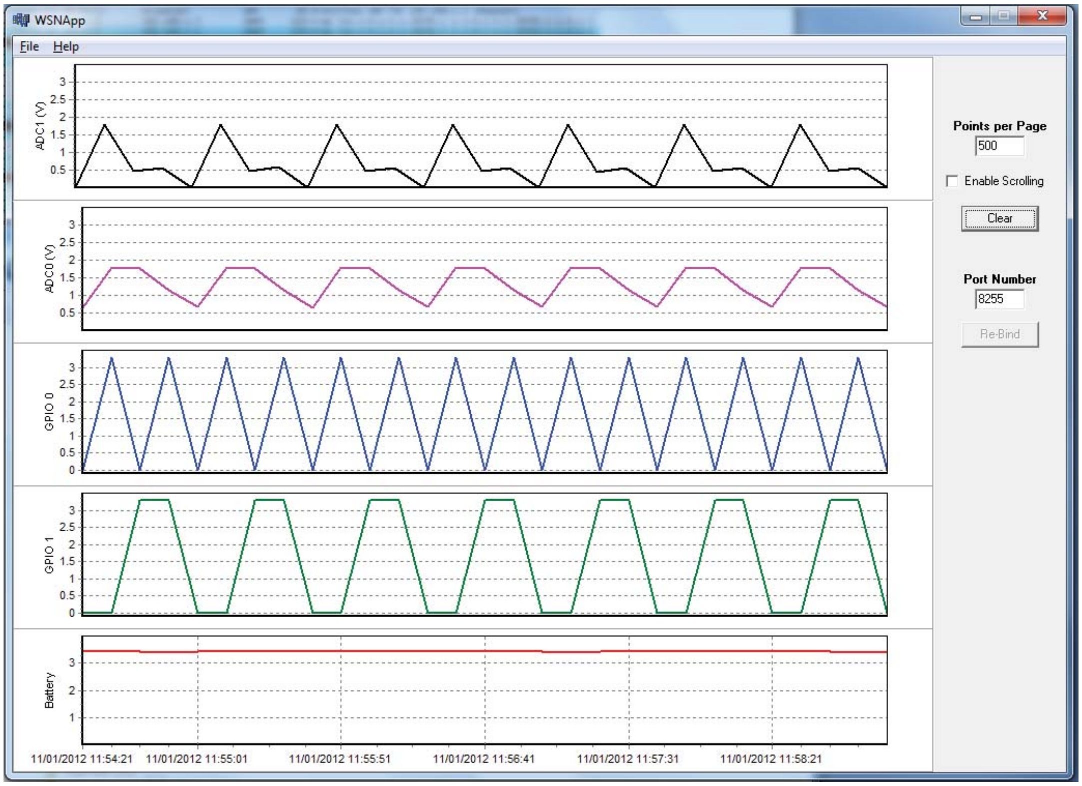


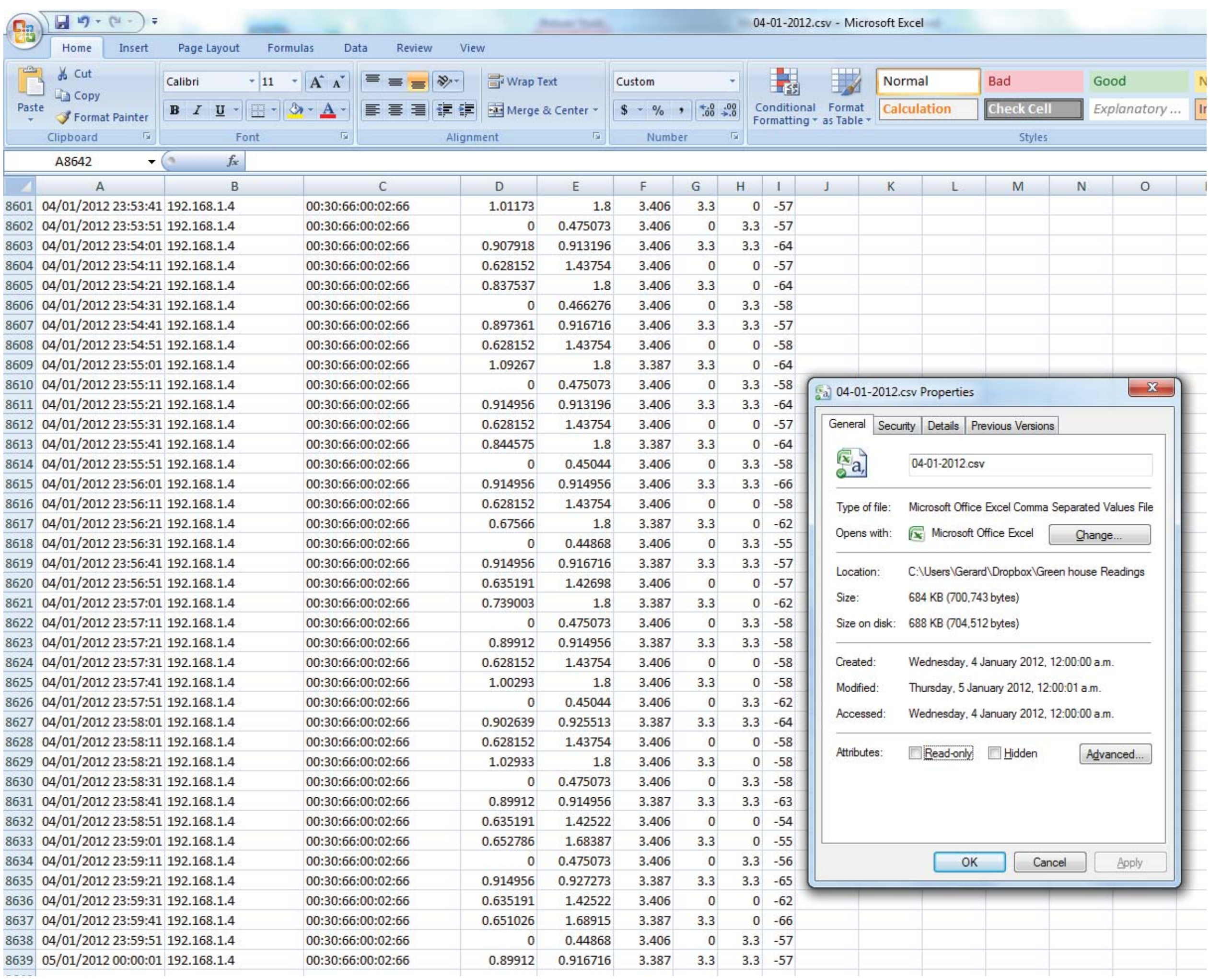
Figure 110: WSNDemo Application Based on Provided Source Code to Log Data

The WSNDemo program runs as the sensor server on Port 8255 and it continues to graph the received data (Figure 110) as the source code allowed but now also logs values for use and analysis. It is important to note that only one program at a time can run as the sensor server. However, multiple modules can have their IO Report data logged to the CSV file (Figure 111) using the same WSNDemo application.

TIMESTAMP	SOURCE_IP_ADDRESS	SOURCE_MAC_ADDRESS	ADC0	ADC1	BATTERY	GPIO0	GPIO1	RSSI
14/09/2011 14:11:21	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-53
14/09/2011 14:11:24	192.168.1.4	00:30:66:00:02:7E	0.659824	0.689736	3.332	0	0	-38
14/09/2011 14:11:31	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-56
14/09/2011 14:11:34	192.168.1.4	00:30:66:00:02:7E	0.665103	0.695015	3.332	0	0	-42
14/09/2011 14:11:41	192.168.1.3	00:30:66:00:03:70	1.39179	0.939589	3.625	3.3	3.3	-53
14/09/2011 14:11:44	192.168.1.4	00:30:66:00:02:7E	0.906158	0.41173	3.332	0	3.3	-42
14/09/2011 14:11:51	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-54
14/09/2011 14:11:54	192.168.1.4	00:30:66:00:02:7E	0.855132	0.41349	3.332	0	3.3	-42
14/09/2011 14:12:01	192.168.1.3	00:30:66:00:03:70	0.885044	1.02581	3.625	0	0	-53
14/09/2011 14:12:04	192.168.1.4	00:30:66:00:02:7E	0.659824	0.695015	3.332	0	0	-42

Figure 111: Logged Data from CSV File Displayed in Microsoft Excel where each Node Sends Data at Regular 10 Second Intervals

This current configuration creates relatively small sized files with logged data containing 8639 (one module) instances with 690KB file size (Figure 112). Similarly tests performed show that for logged data containing 17252 instances (two modules) have a file size of 1.2MB. The logged data includes values for Timestamp, Source IP Address, Source MAC Address, ADC0 value, ADC1 value, Battery/Supply Voltage, GPIO0 and GPIO1 values and RSSI. The MAC address is logged as well as IP address, as data can be sent unsolicited and the MAC address being quite unique is provided to identify the sender. This is particularly helpful in situations where DHCP is used and the IP address is initially unknown or if the sender's IP address has been exchanged for Network Address Translation NAT [52].



	A	B	C	D	E	F	G	H	I
8601	04/01/2012 23:53:41	192.168.1.4	00:30:66:00:02:66	1.01173	1.8	3.406	3.3	0	-57
8602	04/01/2012 23:53:51	192.168.1.4	00:30:66:00:02:66	0	0.475073	3.406	0	3.3	-57
8603	04/01/2012 23:54:01	192.168.1.4	00:30:66:00:02:66	0.907918	0.913196	3.406	3.3	3.3	-64
8604	04/01/2012 23:54:11	192.168.1.4	00:30:66:00:02:66	0.628152	1.43754	3.406	0	0	-57
8605	04/01/2012 23:54:21	192.168.1.4	00:30:66:00:02:66	0.837537	1.8	3.406	3.3	0	-64
8606	04/01/2012 23:54:31	192.168.1.4	00:30:66:00:02:66	0	0.466276	3.406	0	3.3	-58
8607	04/01/2012 23:54:41	192.168.1.4	00:30:66:00:02:66	0.897361	0.916716	3.406	3.3	3.3	-57
8608	04/01/2012 23:54:51	192.168.1.4	00:30:66:00:02:66	0.628152	1.43754	3.406	0	0	-58
8609	04/01/2012 23:55:01	192.168.1.4	00:30:66:00:02:66	1.09267	1.8	3.387	3.3	0	-64
8610	04/01/2012 23:55:11	192.168.1.4	00:30:66:00:02:66	0	0.475073	3.406	0	3.3	-58
8611	04/01/2012 23:55:21	192.168.1.4	00:30:66:00:02:66	0.914956	0.913196	3.406	3.3	3.3	-64
8612	04/01/2012 23:55:31	192.168.1.4	00:30:66:00:02:66	0.628152	1.43754	3.406	0	0	-57
8613	04/01/2012 23:55:41	192.168.1.4	00:30:66:00:02:66	0.844575	1.8	3.387	3.3	0	-64
8614	04/01/2012 23:55:51	192.168.1.4	00:30:66:00:02:66	0	0.45044	3.406	0	3.3	-58
8615	04/01/2012 23:56:01	192.168.1.4	00:30:66:00:02:66	0.914956	0.914956	3.406	3.3	3.3	-66
8616	04/01/2012 23:56:11	192.168.1.4	00:30:66:00:02:66	0.628152	1.43754	3.406	0	0	-58
8617	04/01/2012 23:56:21	192.168.1.4	00:30:66:00:02:66	0.67566	1.8	3.387	3.3	0	-62
8618	04/01/2012 23:56:31	192.168.1.4	00:30:66:00:02:66	0	0.44868	3.406	0	3.3	-55
8619	04/01/2012 23:56:41	192.168.1.4	00:30:66:00:02:66	0.914956	0.916716	3.387	3.3	3.3	-57
8620	04/01/2012 23:56:51	192.168.1.4	00:30:66:00:02:66	0.635191	1.42698	3.406	0	0	-57
8621	04/01/2012 23:57:01	192.168.1.4	00:30:66:00:02:66	0.739003	1.8	3.387	3.3	0	-62
8622	04/01/2012 23:57:11	192.168.1.4	00:30:66:00:02:66	0	0.475073	3.406	0	3.3	-58
8623	04/01/2012 23:57:21	192.168.1.4	00:30:66:00:02:66	0.89912	0.914956	3.387	3.3	3.3	-58
8624	04/01/2012 23:57:31	192.168.1.4	00:30:66:00:02:66	0.628152	1.43754	3.406	0	0	-58
8625	04/01/2012 23:57:41	192.168.1.4	00:30:66:00:02:66	1.00293	1.8	3.406	3.3	0	-58
8626	04/01/2012 23:57:51	192.168.1.4	00:30:66:00:02:66	0	0.45044	3.406	0	3.3	-62
8627	04/01/2012 23:58:01	192.168.1.4	00:30:66:00:02:66	0.902639	0.925513	3.387	3.3	3.3	-64
8628	04/01/2012 23:58:11	192.168.1.4	00:30:66:00:02:66	0.628152	1.43754	3.406	0	0	-58
8629	04/01/2012 23:58:21	192.168.1.4	00:30:66:00:02:66	1.02933	1.8	3.406	3.3	0	-58
8630	04/01/2012 23:58:31	192.168.1.4	00:30:66:00:02:66	0	0.475073	3.406	0	3.3	-58
8631	04/01/2012 23:58:41	192.168.1.4	00:30:66:00:02:66	0.89912	0.914956	3.387	3.3	3.3	-63
8632	04/01/2012 23:58:51	192.168.1.4	00:30:66:00:02:66	0.635191	1.42522	3.406	0	0	-54
8633	04/01/2012 23:59:01	192.168.1.4	00:30:66:00:02:66	0.652786	1.68387	3.406	3.3	0	-55
8634	04/01/2012 23:59:11	192.168.1.4	00:30:66:00:02:66	0	0.475073	3.406	0	3.3	-56
8635	04/01/2012 23:59:21	192.168.1.4	00:30:66:00:02:66	0.914956	0.927273	3.387	3.3	3.3	-65
8636	04/01/2012 23:59:31	192.168.1.4	00:30:66:00:02:66	0.635191	1.42522	3.406	0	0	-62
8637	04/01/2012 23:59:41	192.168.1.4	00:30:66:00:02:66	0.651026	1.68915	3.387	3.3	0	-66
8638	04/01/2012 23:59:51	192.168.1.4	00:30:66:00:02:66	0	0.44868	3.406	0	3.3	-57
8639	05/01/2012 00:00:01	192.168.1.4	00:30:66:00:02:66	0.89912	0.916716	3.387	3.3	3.3	-57

Figure 112: Logged Data Containing 8639 (one module) Instances with 690KB File Size

7.9. GRAPHICALLY PLOTTING THE DATA

A program was written to graphically plot the recorded data of the system (Figure 113). The application was designed using Visual C#, a high level, object-oriented programming language made available by Massey University and MSDN. The written application was developed to run in conjunction with the other executed programs. It uses the ZedGraph class library, a powerful and free charting solution that features full, detailed customization capabilities [85]. Zed Graph is used for drawing 2D line graphs and in order to use ZedGraph the zedgraph.dll is required and can be downloaded from (http://zedgraph.sourceforge.net/index.html).

There are existing systems that could be used for plotting of data. However, it is seen they were mainly designed and aimed at skilled and experienced operators. Therefore new operators would be required to undergo training in order to plot and save the data results from the system.

This simple but effective plotting application was designed to tackle this problem. The designed application is straightforward and convenient. Inexperienced users should be able to effectively operate it to allow for future referencing and analysis. The application allows for graphing of historical data stored in the CSV log file. It has ten Tabs for the data of interest such as: Temperature, Humidity, Light, Pressure, Water Level, Soil Moisture, Battery, RSSI, as well the ADC values of the 2 free inputs that may be used in the future.

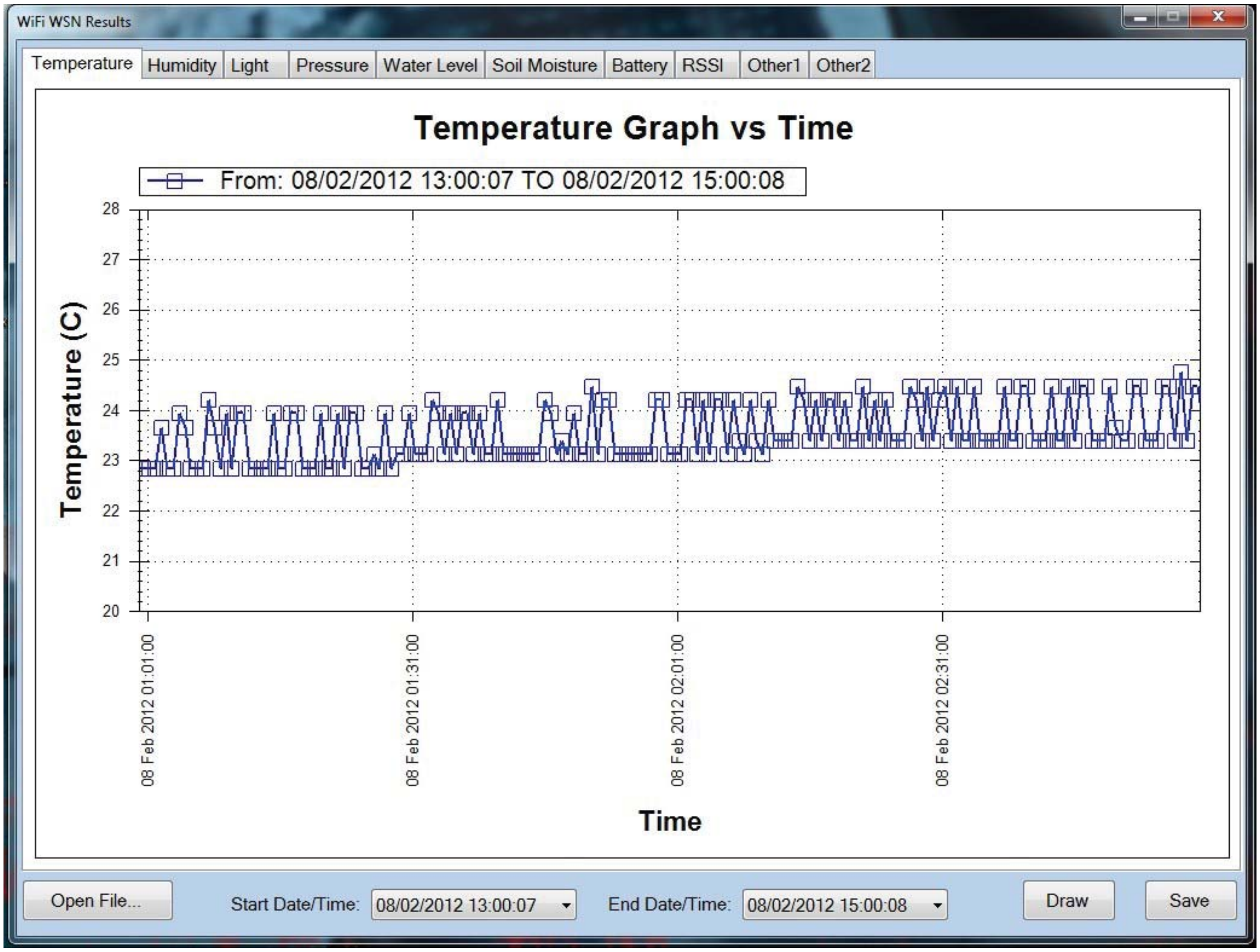


Figure 113: Plot of Temperature using Written Program

Upon selecting the file, the sought after time period for graphing can easily be selected by setting the "Start Date/Time" and "End Date/Time" values in the dropdown boxes. When the "Draw" button is clicked the various line graphs are updated with the results for the selected time period. Clicking the "Save" button saves all existing ten graphs as separate .png images. The saved images (Figure 114) have resolutions of 300dpi and allows for future reference/analysis and be selected for printing by the user.

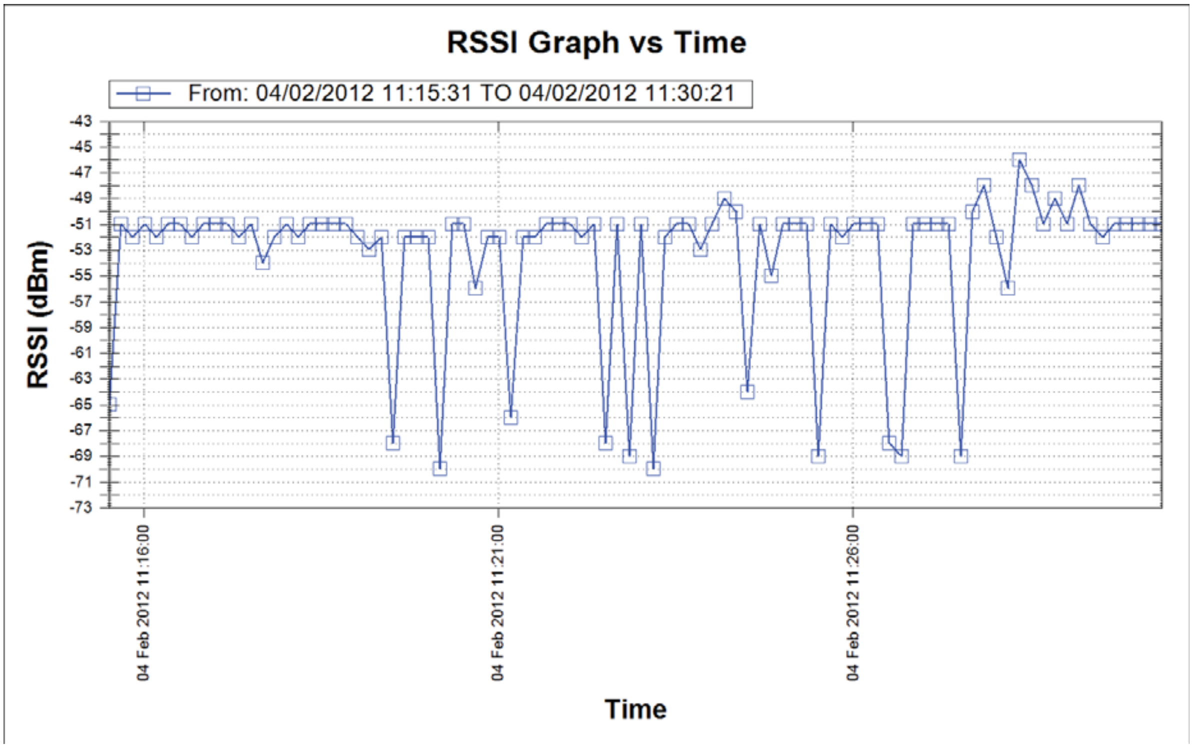


Figure 114: Example of Saved png Image of RSSI Values using Written Program

7.10. DATABASE

The main purpose of using a database is to store historical data for future research and analysis. Therefore a designed database must be simple and easy to follow so that the user can easily retrieve recorded data in the future. The CSV file is exported into an Access database where the design of the database for this project is shown in (Table 23).

Table 23: Database Field Description

Field	Descriptions	Data Type
RECORD_NUMBER	Is used to keep track of recorded data	Long Integer
TIMESTAMP	Displays the time and date of when the data was collected	Date/Time
SOURCE_IP_ADDRESS	Displays the origin of recorded data	Text
SOURCE_MAC_ADDRESS	Displays the origin of recorded data	Text
ADC0	ADC0 readings	Double
ADC1	ADC1 readings	Double
BATTERY	Displays the battery /Supply Voltage status of Station	Double
GPIO0	GPIO0 Reading	Double
GPIO1	GPIO1 Reading	Double
RSSI	Received Signal Strength Indicator	Long Integer

The CSV file allows for straightforward exporting into Microsoft Access (Figure 115), where the first row of the CSV contains the field names. Once exported in to Microsoft Access the data can be queried, have calculations performed and graphed. Using the MAC address and GPIO values, queries can be performed to distinguish between the different modules and sensors measurements.

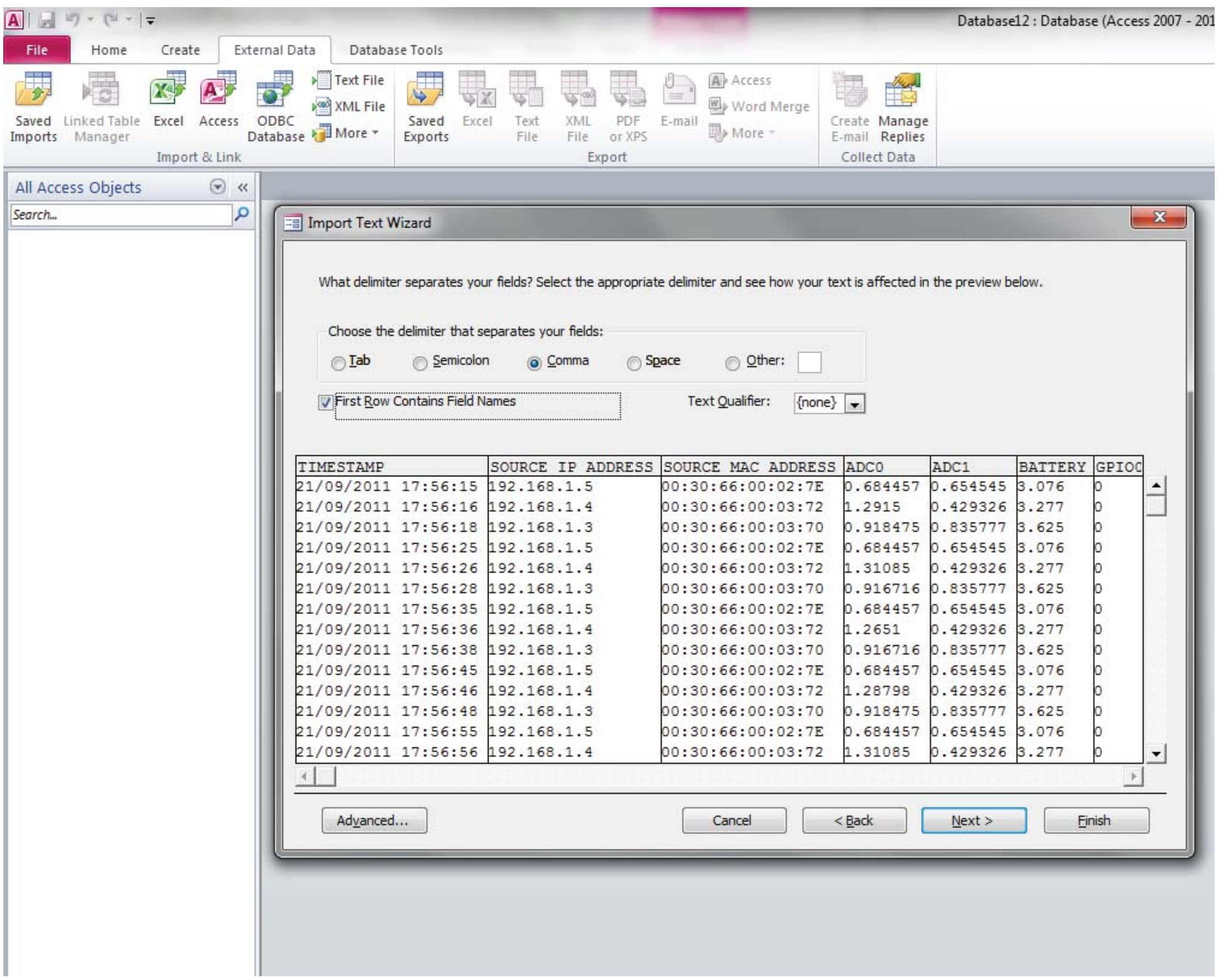


Figure 115: Exporting Logged Data from CSV File into Microsoft Access

Depending on the data exported into Microsoft Access from the CSV file, it can be queried and calculations performed. Graphs can be created and averaged over various periods based upon TIMESTAMP.

7.11. EXPERIMENTAL RESULTS

The developed system was deployed in a hydroponic greenhouse. The results from the sensor outputs were stored into a CSV file. The experimental results obtained from the system are shown below. Saved png images can easily be compared (Figure 116).

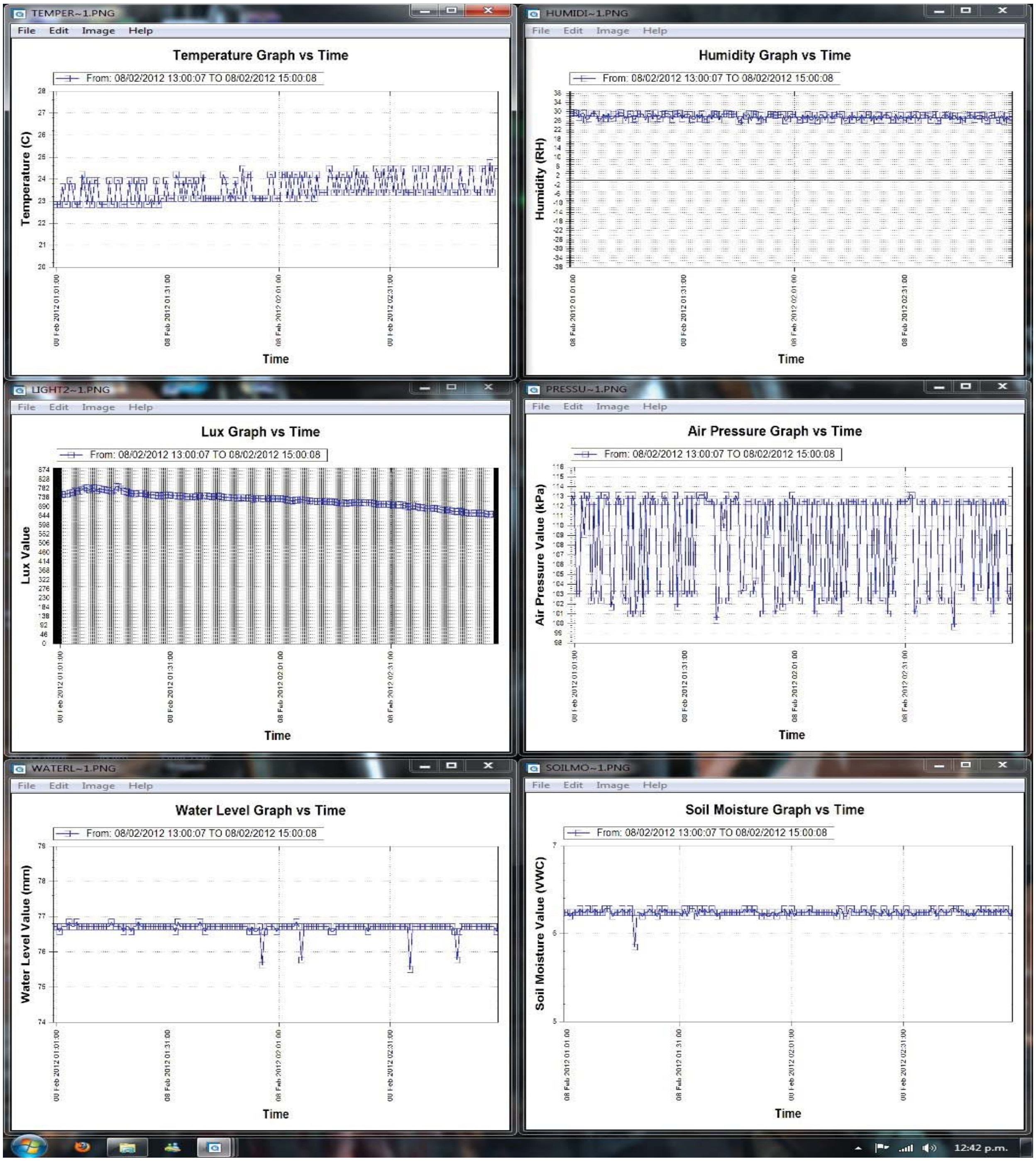


Figure 116: Saved Graphs from the Program can be easily Compared

Temperature

As previously discussed, temperature affects growth of agricultural products with regards to germination, sprouting, flowering and fruit development. Measurements acquired by the system and logged for temperature within the enclosed Hydroponics greenhouse can be seen over a 24 hour period (Figure 117). The maximum and minimum measured values can be observed along with the various ongoing changes.

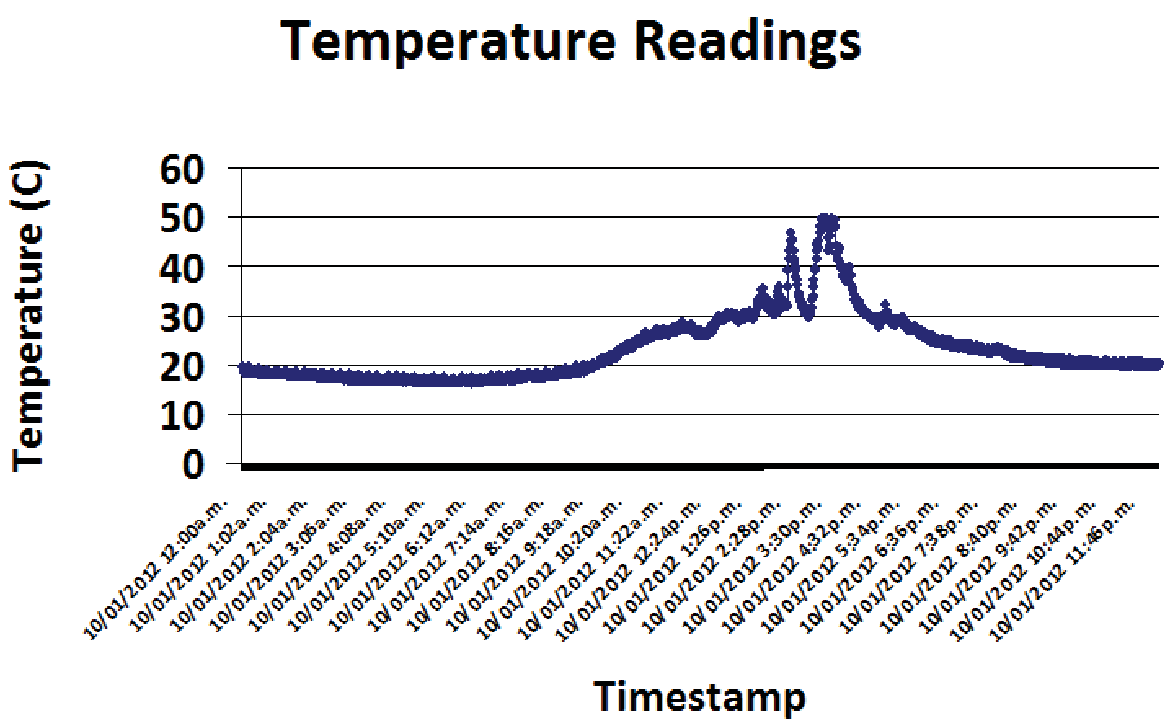


Figure 117: Logged Data for Temperature Sensor Output

Light

Light and its duration are of significance as it affects the growth processes of farm and plants in agricultural environments. Monitoring light for control and management of light sources can play a role with flowering, blooming and ripening of produce. Measurements acquired by the system and logged for light show particular periods of darkness and light. It can also be seen that temperature increases (Figure 117) occurred during periods where light was present.

Measurements logged for light within an enclosed hydroponic area can be seen over approximately a 24 hour period (Figure 118).

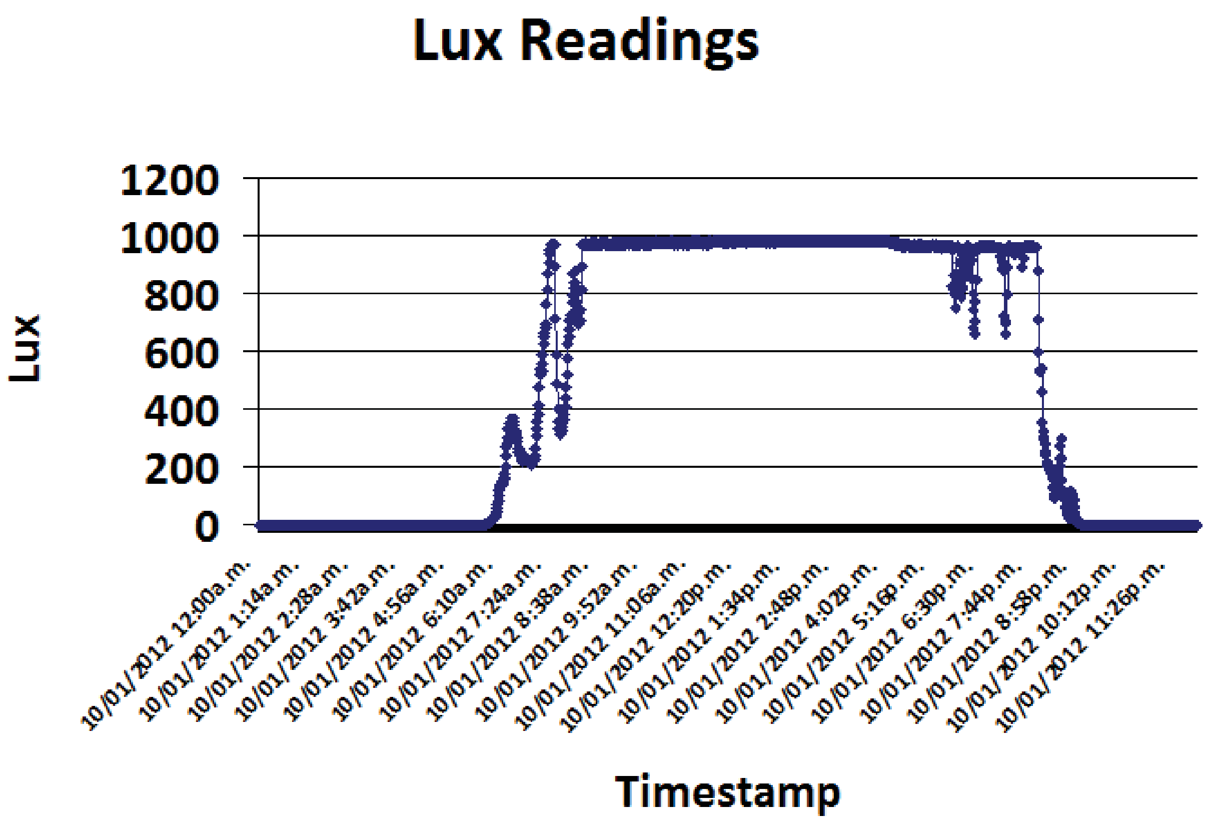


Figure 118: Logged Data for Light Sensor

Humidity

Agricultural products can suffer when humidity is too low or high. If humidity is low for extended periods, loss of water from leaves can be more rapid than replacement. Similarly if humidity is high for extended periods risk of disease can increase.

Measurements logged for humidity within an enclosed hydroponic area can be seen over a 24 hour period (Figure 119).

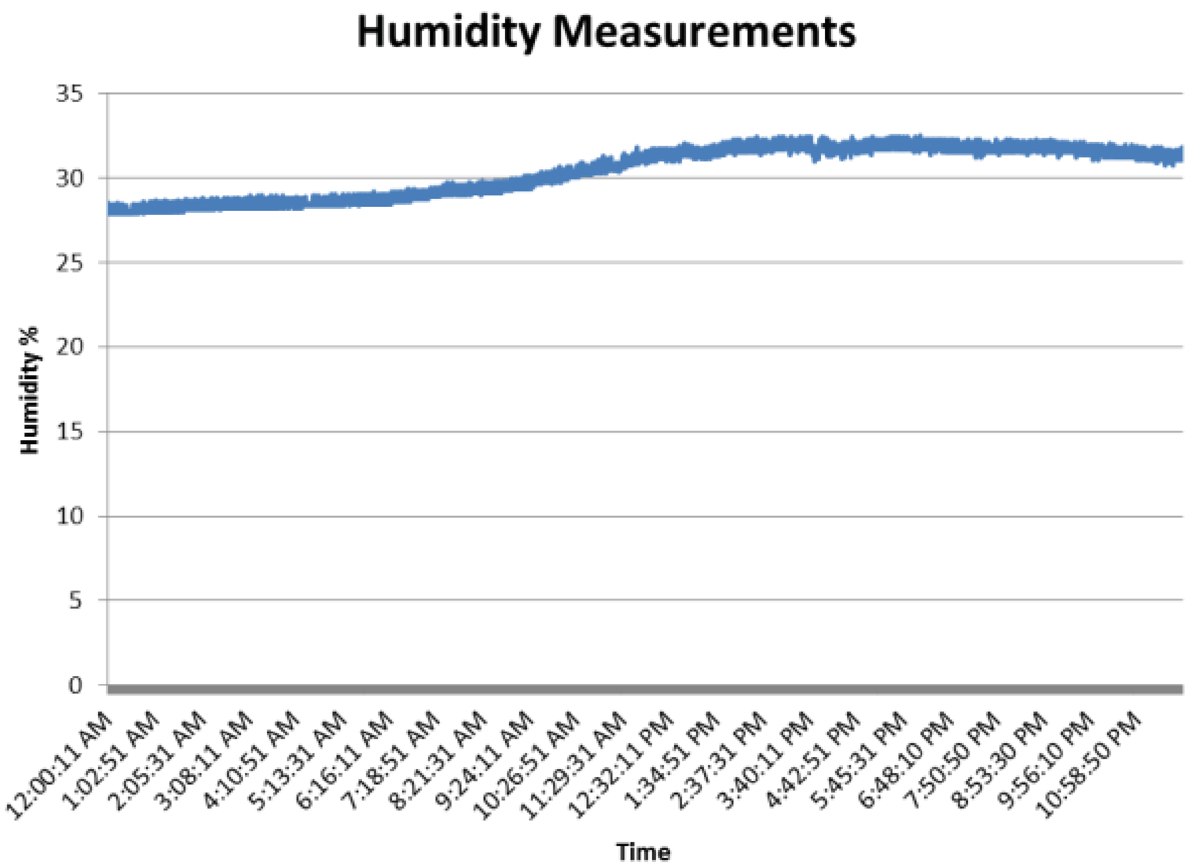


Figure 119: Logged Data for Humidity Sensor

Air Pressure

Air pressure measurement is a variable of interest, as it has relationship to other weather factors that might be used for prediction of upcoming changes in the environment. Low pressure is often associated with poor weather, with a rapid change in pressure occurring meaning possible radical weather changes.

Measurements logged for pressure within an enclosed hydroponic area can be seen over an approximately 24 hour period (Figure 120).

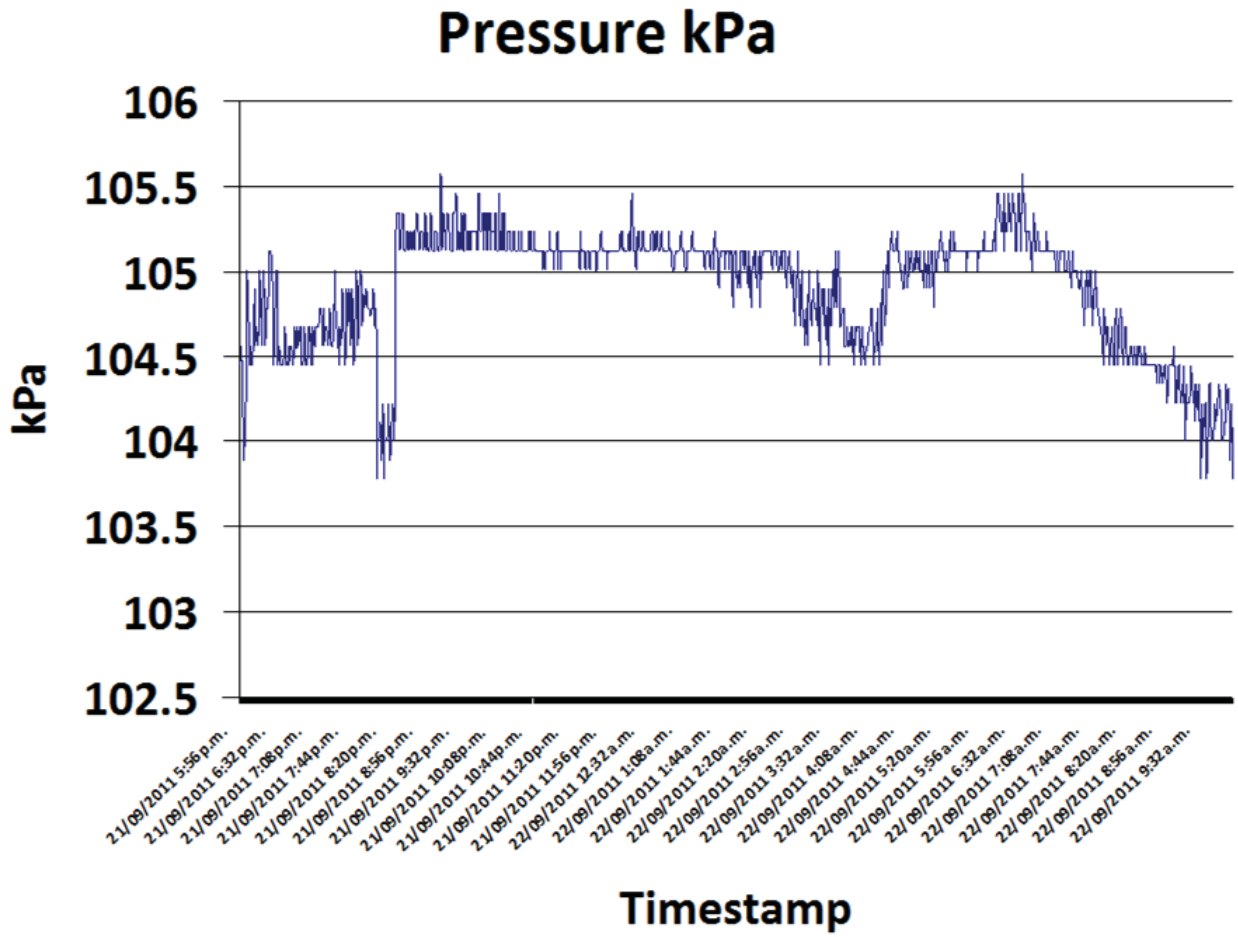


Figure 120: Logged Data for Pressure Sensor

Soil Moisture and Water Level

The measurement of water/nutrient level or rainfall along with soil moisture is of significance to the survival and growth of agricultural products. Plants that have sufficient water have vigorous growth in comparison to those in dry conditions.

Measurements logged for soil moisture within an enclosed greenhouse can be seen over a 10 Day period (Figure 121). It is observed that there is a gradual decrease in soil moisture over time.

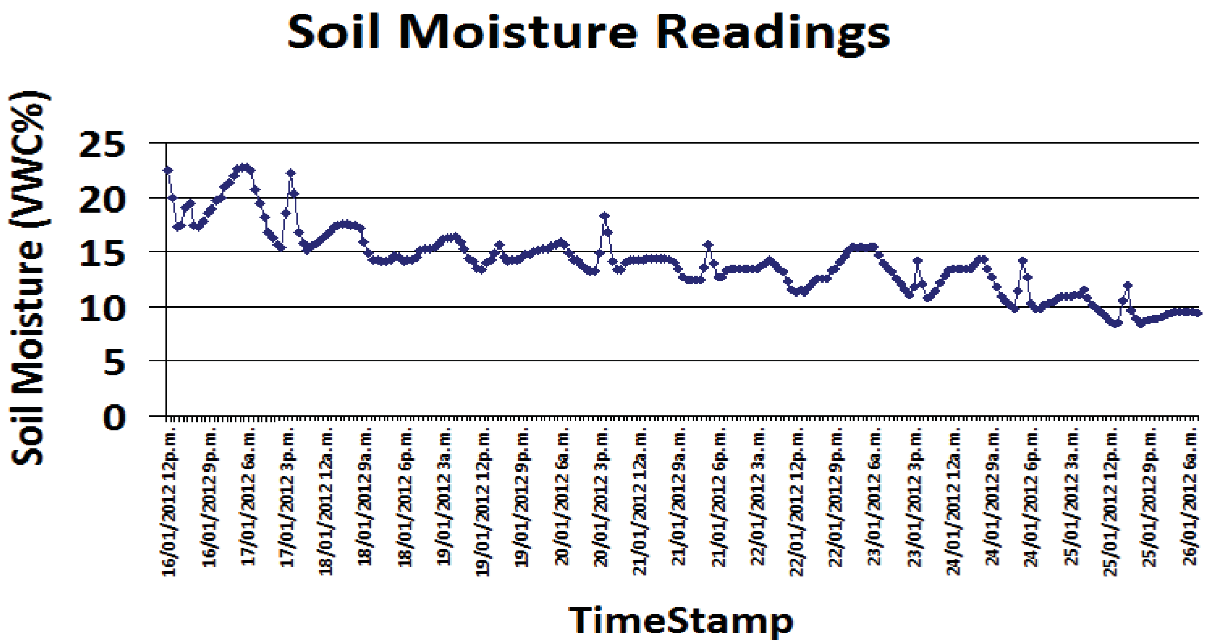


Figure 121: Logged data for VWC over a 10 Day Period

Measurements logged for water level readings within an enclosed hydroponic area can be seen over an approximately 10 Day period (Figure 122). It is observed that there is a gradual decrease in water level over time. Water level and soil moisture both decrease within the same environment.

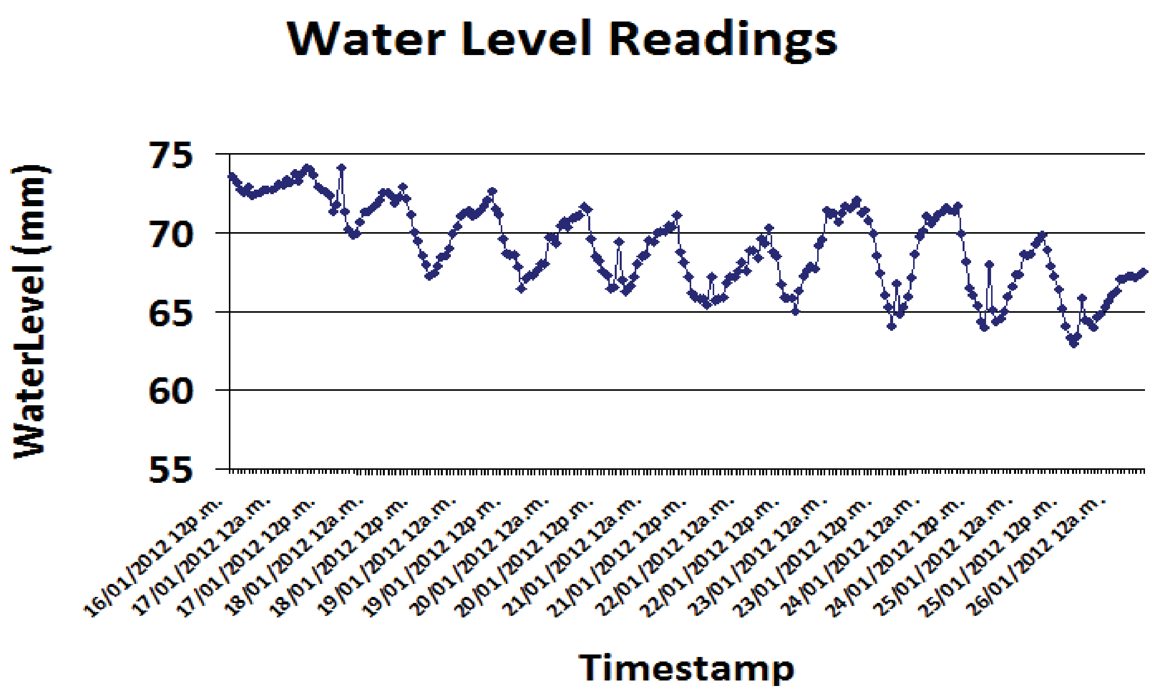


Figure 122: Logged data for Water Level over a 10 Day Period

8) CONCLUSIONS & FUTURE DEVELOPMENTS

This report presents research on an application of a Wi-Fi based wireless sensor network (WSN) for agricultural monitoring. The proposed system consists of three stations: a Sensor Station, Access point and Central Server Station.

The sensor station acts as a data acquisition unit capable of measuring six different climate parameters, such as temperature, relative humidity, presence of light, air pressure, soil moisture and water/nutrient level. Consideration for two additional sensor inputs has been made, although the system implements only six sensors. The access point is a commercially available 802.11G router. It is responsible for controlling the flow of data and instructions between the sensor station and the central server station. The central server station is the main controller of WSN system. It carries out various tasks such as data collection, data storage, and configuration of sensor nodes deployed. Data is sent by the server to configure WSN802G modules wirelessly.

The WSN802G modules capabilities and function were thoroughly investigated. Analysis was done on the communication of information within the WSN with logs and wireless protocol analyzers such as Wireshark. This showed one of the strengths of Wi-Fi and IP technology systems, was readily available tools which can be used to monitor and control the Wi-Fi system. It was seen that the WSN802G modules allows for relatively easy connection to nodes and communication. The system can be operated with standard commercial products that are commonly implemented.

The WSN802G reliability and feasibility were also investigated and the distance attainable from the WSN802G module using stock standards integrated antenna was obtained. Additional tests were performed where The Received Signal Strength Indicator (RSSI) of WSN802G wireless module was found to be related to distance/displacement between router and WSN802G module. It was shown that during testing the RSSI values can vary when placed in different environments, as in a fruit orchard environment and clear line of sight. It was discovered that obstructions such as trees were the main causes of diminished signal strength. Despite this, indications are that Wi-Fi can be used as a solution to overcome the traditional method of manual collection of data. It also addresses problems faced by the traditional use of wires and cables to distribute sensors. The sensor node can allow for battery operation, relocation repositioning and addition of new sensors. The system aims to reduce the cost and effort of wiring and to enhance the flexibility and mobility of the selected sensing points.

Measured results were attained in order to derive a general expression of energy consumption of the WSN802G, where it takes into account the times the module spends in different known states. An oscilloscope was used, as it is an instrument that has abilities to measure short duration signals in different frequencies. This is particularly important as signal/pulse duration will be quite short in the magnitude of (msec). Most voltmeters are calibrated to measure signals only in DC or in AC, and averaging would not provide adequate results. In particular, energy consumption differs when different transmissions are sent and energy consumed with Linkup /IO transmissions are different and lower in magnitude to Config/Linkup /IO transmissions.

An important aspect of the design was to keep the size of the node compact. Therefore, a large proportion of circuitry components used for the sensor node are either surface-mounted or very small in size. The final design of the sensor node includes the circuitry for automatic sensor switching of the sensing node. These characteristics make the developed system respectable in terms of size, maintenance requirements and power consumption. At present the project investigated a simple solar harvesting system and power management.

Investigation into interfacing the Novel Planar Electromagnetic Sensors to the WSN802G ADC was performed. This involved implementing a XR2206 - Generator, Monolithic IC as a signal generator to be used with the sensor. The signal generator system allows for easy adjustment of the frequency and amplitude inputted to the sensor, where the changes occur quickly and incorporation is straightforward. A gain and phase measurement system was investigated based upon the use of an AD8302 Gain Phase Detector IC. It was utilized to measure the gain and phase difference between the original sine wave from signal generator and the sensor output. The AD8302 provides voltage outputs up to 1.8V for representation of gain and phase that could be used with the WSN802G ADCs. The results of the project investigation show the AD8302 can provide accurate values for phase and gain during testing. However, further investigation is required for getting signal to AD8302 within usable ranges.

In conclusion, agricultural environment monitoring systems are an attractive opportunity here in New Zealand, particularly wireless sensor systems which use Wi-FI such as the WSN802G module. This thesis can therefore be used as a good reference source for further integrating/developing similar work/ projects using the Wi-Fi WSN802G modules. The thesis investigates and explains in depth the use of Wi-Fi WSN802G modules and its abilities. The current system performs well for transferring and logging of values from the various sensor nodes using standard commercial products and works in conjunction with equipment already in use. It allows for relatively easy connection to nodes and communication.

This thesis has provided a comprehensive report on the design process and implementation of a Wi-Fi based wireless agricultural monitoring system. Regardless, there is a need for further study to improve the system capability. The following are some recommendations for possible future work:

- Combining the various applications into one single dedicated application for control, logging and analyses of transmitted results where user interaction is kept to a minimum. It should have a user friendly GUI program with extra features to allow the system to directly alert the user of any abnormal changes in the greenhouse environment

- Investigation into use of high gain antenna within the WSN in order to gain better distance for the system.
- Addition of more sensors to monitor other environmental parameters such as soil pH level, carbon Dioxide (CO2) and oxygen (O) while allowing for replacement of current sensors if a wider range of measurement is desired.
- Integration of additional monitoring devices such as a Wi-Fi camera to monitor growth of agricultural product.
- Development of protective casing for wireless sensor nodes.
- Current system monitors only, however implementing the sensor nodes as an agricultural control system using either GPIO values or serial communication is of interest.
- Further investigation of power harvesting and battery charging using intelligent systems.
- Further investigation into integration of the nitrate detection sensor with the WSN while keeping accuracy and precision of measurements.

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10) PUBLICATIONS

A. PROCEEDING AND CONFERENCE PAPER

1. G. R. Mendez, A. M. Yunus and S. C. Mukhopadhyay, " A Wi-Fi based Smart Wireless Sensor Network for an Agricultural Environment", in Proceedings of the Fifth International Conference on Sensing Technology, ISBN 978-1-4577-0167-2, Massey University, Palmerston North, New Zealand, pp. 421-426, November 28 – December 1, 2011.

2. M. A. M. Yunus, G. R. Mendez and S. C. Mukhopadhyay, "Development of a Low Cost System for Nitrate and Contamination Detections in Natural Water Supply based on a Planar Electromagnetic Sensor," in Proceedings of IEEE I2MTC 2011 Conference, IEEE Catalog number CFP11MT-CDR, ISBN 978-1-4244-7934-4, Hangzhou China, pp. 1557-1562, May 10-12, 2011.

3. G. R. Mendez, A. M. Yunus and S. C. Mukhopadhyay, " A WiFi based Smart Wireless Sensor Network for Monitoring an Agricultural Environment", in Proceedings IEEE I2MTC 2012 Conference, [Accepted]

B. SEMINAR/PRESENTATION

1. G. R. Mendez, A. M. Yunus and S. C. Mukhopadhyay, " A Wi-Fi based Smart Wireless Sensor Network for an Agricultural Environment", Fifth International Conference on Sensing Technology, Presentation on the 1st Dec 2011 Massey University, Palmerston North, New Zealand,

11) APPENDIX- WSN802G DATA SHEET

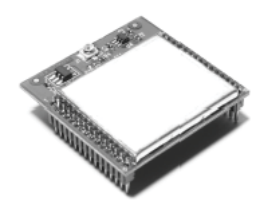
DEVELOPMENT KIT
(Info Click here)

WSN802G

802.11g Wireless Sensor Network Module

- ***Small Size, Light Weight, Low Cost***
- ***7.5 µA Sleep Current Supports Battery Operation***
- ***Timer and Event Triggered Auto-reporting Capability***
- ***Analog, Digital, Serial and SPI I/O for Sensor Applications***
- ***-40 to +85 °C Operating Temperature Range***
- ***FCC, Canadian IC and ETSI Certified for Unlicensed Operation***

The WSN802G transceiver module is a low cost, robust solution for 802.11g sensor networks. The WSN802G's very low sleep current makes long life battery operation practical. The WSN802G module includes analog, digital, serial and SPI I/O, providing the flexibility and versatility needed to serve a wide range of sensor network applications. The WSN802G module is easy to integrate and is compatible with standard 802.11b/g access points.



WSN802G Absolute Maximum Ratings

Rating	Value	Units
Input/Output Pins Except ADC Inputs	-0.5 to +3.63	V
ADC Input Pins	-0.5 to 1.98	V
Non-Operating Ambient Temperature Range	-40 to +85	°C

WSN802G Electrical Characteristics

Characteristic	Sym	Notes	Minimum	Typical	Maximum	Units
Operating Frequency Range			2401		2474	MHz
Spread Spectrum Method				Direct Sequence		
RF Chip Rate				11		Mcps
RF Data Rates				1, 2, 5.5, 11		Mbps
Modulation Type				BPSK at 1 Mbps, QPSK at 2 Mbps, CCK at 5.5 and 11 Mbps		
Number of RF Channels				11		
RF Channel Spacing				5		MHz
Receiver Sensitivity, 8% PER:						
1 Mbps RF Data Rate				-92		dBm
2 Mbps RF Data Rate				-90		dBm
5.5 Mbps RF Data Rate				-84		dBm
11 Mbps RF Data Rate				-81		dBm
RF Transmit Power				10		mW
RF Connector				U.FL Coaxial Connector		
Optimum Antenna Impedance				50		Ω

WSN802G Electrical Characteristics

Characteristic	Sym	Notes	Minimum	Typical	Maximum	Units
ADC Input Range			0		1.8	V
ADC Input Resolution				10		bits
ADC Input Impedance			1			MΩ
PWM Output Resolution					16	bits
Data Serial Port Baud Rates			1.2, 2.4, 4.8, 9.6 (default), 19.2, 28.8, 38.4, 57.6, 76.8, 115.2, 230.4, 460.8, 921.6			kbps
Diagnostic Serial Port Baud Rates			1.2, 2.4, 4.8, 9.6 (default), 19.2, 28.8, 38.4, 57.6, 76.8, 115.2			kbps
Serial Peripheral Interface (SPI) Data Rate, Master Mode					11	Mbps
Serial Peripheral Interface (SPI) Data Rate, Slave Mode					2	Mbps
Digital I/O:						
Logic Low Input Level			-0.3		0.7	V
Logic High Input Level			2.24		V_{CC}	V
Input Pull Up Resistor			50		1000	KΩ
Logic Low Output Level			0		0.4	V
Logic High Output Level			2.4		V_{CC}	V
Power Supply Voltage Range	V_{CC}		+3		+3.63	Vdc
Power Supply Voltage Ripple					10	mV_{P-P}
Receive Mode Current					150	mA
Transmit Mode Current					200	mA
Sleep Mode Current				7.5		µA
WSN802GC Mounting			Reflow Soldering			
WSN802GP Mounting			Socket			
Operating Temperature Range			-40		85	°C
Operating Relative Humidity Range, Non-condensing			10		90	%

CAUTION: Electrostatic Sensitive Device. Observe precautions when handling.

WSN802G Electrical Characteristics

Characteristic	Sym	Notes	Minimum	Typical	Maximum	Units
ADC Input Range			0		1.8	V
ADC Input Resolution				10		bits
ADC Input Impedance			1			MΩ
PWM Output Resolution					16	bits
Data Serial Port Baud Rates			1.2, 2.4, 4.8, 9.6 (default), 19.2, 28.8, 38.4, 57.6, 76.8, 115.2, 230.4, 460.8, 921.6			kbps
Diagnostic Serial Port Baud Rates			1.2, 2.4, 4.8, 9.6 (default), 19.2, 28.8, 38.4, 57.6, 76.8, 115.2			kbps
Serial Peripheral Interface (SPI) Data Rate, Master Mode					11	Mbps
Serial Peripheral Interface (SPI) Data Rate, Slave Mode					2	Mbps
Digital I/O:						
Logic Low Input Level			-0.3		0.7	V
Logic High Input Level			2.24		V_{CC}	V
Input Pull Up Resistor			50		1000	KΩ
Logic Low Output Level			0		0.4	V
Logic High Output Level			2.4		V_{CC}	V
Power Supply Voltage Range	V_{CC}		+3		+3.63	Vdc
Power Supply Voltage Ripple					10	mV_{P-P}
Receive Mode Current					150	mA
Transmit Mode Current					200	mA
Sleep Mode Current				7.5		µA
WSN802GC Mounting			Reflow Soldering			
WSN802GP Mounting			Socket			
Operating Temperature Range			-40		85	°C
Operating Relative Humidity Range, Non-condensing			10		90	%

CAUTION: Electrostatic Sensitive Device. Observe precautions when handling.

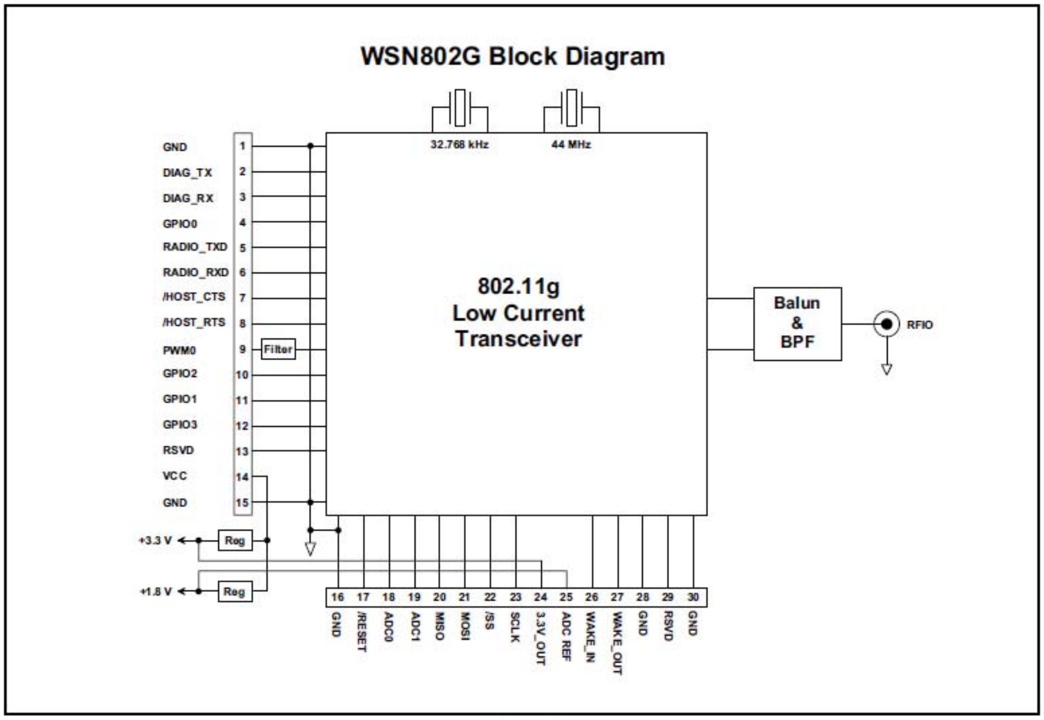


Figure 1

WSN802G Hardware

The WSN802G operates in the international 2.4 GHz ISM band over the frequency range of 2401-2474 MHz, with a nominal RF output power of 10 mW. The WSN-802G supports four standard 802.11g RF data rates - 1, 2, 5.5 and 11 Mbps.

The WSN802G transceiver module provides a variety of hardware interfaces. There are two serial interfaces, one for data and a second for diagnostics. The data port supports standard serial baud rates from 1.2 to 921.6 kbps, with optional hardware flow control. The diagnostic port supports standard baud rates from 1.2 to 115.2 kbps. The WSN802G also includes an SPI port that supports data rates up to 2 Mbps in slave mode, and up to 11 Mbps in master mode.

The WSN802G includes two 10-bit ADC inputs, one 16-bit PWM (DAC) output, and four general purpose I/O (GPIO) ports to support sensor network applications.

The WSN802G module is available in two mounting configurations. The WSN802GC is designed for solder reflow mounting, and the WSN802GP is designed for plug-in connector mounting.

Rev F WSN802G Firmware

The major firmware components in the WSN802G include the 802.11g stack and the application protocol. The WSN802G acts as a UDP client to a data and/or sensor application running on a network server.

The application protocol supports three operating modes: (1) sleeping sensor node with timer or interrupt auto-reporting, (2) sleeping serial data node with timer or interrupt wake-up and (3) always on sensor or serial data node with auto-reporting. Modes 1 and 2 take full advantage of the very low sleep current capability of the WSN802G. The module sleeps unless the WAKE_IN input is asserted or the *AutoReport* timer fires. A *Wake-Timeout* timer is provided to hold the module awake for a configurable period. The *WakeTimout* timer is held in reset as long as WAKE_IN is asserted, serial data is being received, an RF packet is being sent or received, or if the module is uncommissioned.

The WSN802G asserts WAKE_OUT whenever it is awake to notify its external host. The module also sends an I/O status report automatically each time WAKE_IN is asserted, and/or each time the *AutoReport* timer fires.

WSN802G I/O Pad Descriptions

Pin	Name	I/O	Description
1	GND	-	Power supply and signal ground. Connect to the host circuit board ground.
2	DIAG_TX	O	Diagnostic serial port output.
3	DIAG_RX	I	Diagnostic serial port input.
4	GPIO0	I/O	Configurable digital I/O port 0. An internal weak pull up is provided when configured as an input.
5	RADIO_TXD	O	Serial data output from the radio.
6	RADIO_RXD	I	Serial data input to the radio.
7	/HOST_CTS	O	UART/SPI flow control output. The module sets this line low to indicate it is ready to accept data from the host on the RADIO_RXD or MOSI input. When the module sets this line high, the host must stop sending data.
8	/HOST_RTS	I	UART flow control input. The host sets this line low to allow data to flow from the module on the RADIO_TXD pin. When the host sets this line high, the module will stop sending data to the host.
9	PWM0	O	16-bit pulse-width modulated output 0 with internal low-pass filter. Filter is first-order, with a 159 Hz 3 dB bandwidth, 10K output resistance.
10	GPIO2	I/O	Configurable digital I/O port 2. An internal weak pull up is provided when configured as an input.
11	GPIO1	I/O	Configurable digital I/O port 1. An internal weak pull up is provided when configured as an input.
12	GPIO3	I/O	Configurable digital I/O port 3. An internal weak pull up is provided when configured as an input.
13	RSVD	-	Reserved pin. Leave unconnected.
14	VCC	I	Power supply input, +3.0 to +3.63 Vdc.
15	GND	-	Connect to the host circuit board ground.
16	GND	-	Connect to the host circuit board ground.
17	/RESET	I	Active low module hardware reset.
18	ADC0	I	10-bit ADC input 0. ADC full scale reading can be referenced to the module's +1.8 V regulated supply.
19	ADC1	I	10-bit ADC input 1. ADC full scale reading can be referenced to the module's +1.8 V regulated supply.
20	MISO	I/O	SPI master in, slave out function. This pin is an input when the module is operating as a master, and is an output when the module is operating as a slave.
21	MOSI	I/O	SPI master out, slave in function. This pin is an output when the module is operating as a master, and is an input when the module is operating as a slave.
22	/SS	I/O	SPI active low slave select. This pin is an output when the module is operating as a master, and an input when it is operating as a slave.
23	SCLK	I/O	SPI clock signal. This pin is an output when operating as a master, and an input when operating as a slave.
24	3.3V_OUT	O	Module's +3.3 V regulated supply, available to power external sensor circuits. Current drain on this output should be no greater than 50 mA.
25	ADC_REF	O	Module's +1.8 V regulated supply, used for ratiometric ADC readings. Current drain on this output should be no greater than 10 mA.
26	WAKE_IN	I	Active high interrupt input to wake the module from timer sleep. Can be used to wake module on event, etc.
27	WAKE_OUT	O	Active high output asserted when module wakes from timer sleep. Can be used to wake an external device.
28	GND	-	Connect to the host circuit board ground plane.
29	RSVD	-	Reserved pin. Leave unconnected.
30	GND	-	Connect to the host circuit board ground plane.

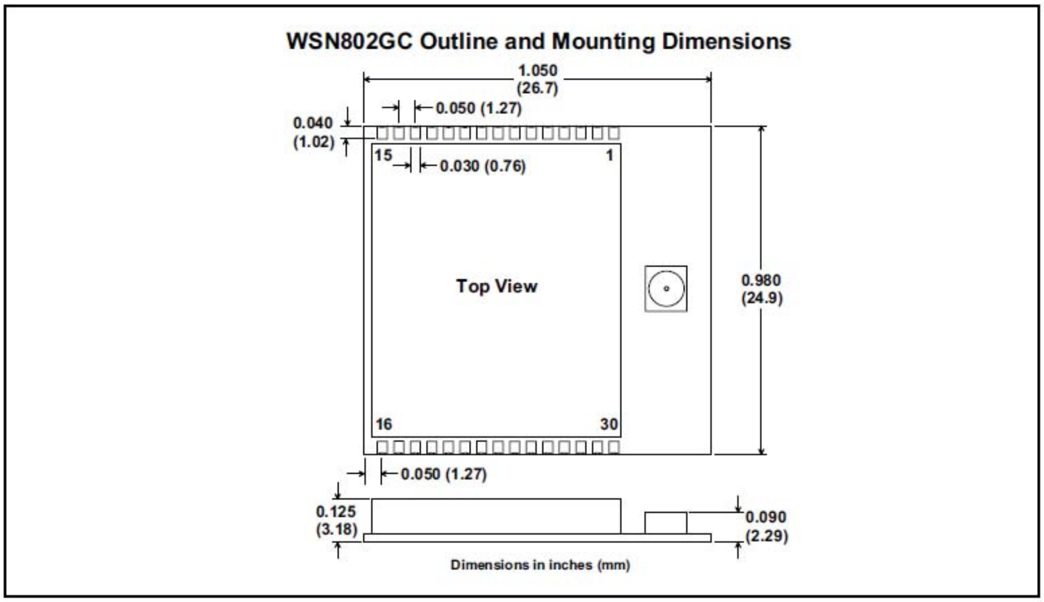


Figure 2

WSN802G Antenna Connector

A U.FL miniature coaxial connector is provided on both WSN802G configurations for connection to the RFIO port. A short U.FL coaxial cable can be used to connect the RFIO port directly to an antenna. In this case the antenna should be mounted firmly to avoid stressing the U.FL coaxial cable due to antenna mounting flexure. Alternately, a U.FL coaxial jumper cable can be used to connect the WSN802G module to a U.FL connector on the host circuit board. The connection between the host circuit board U.FL connector and the antenna or antenna connector on the host circuit board should be implemented as a 50 ohm stripline. Referring to Figure 3, the width of this stripline depends on the thickness of the circuit board between the stripline and the groundplane. For FR-4 type circuit board materials (dielectric constant of 4.7), the width of the stripline is equal to 1.75 times the thickness of the circuit board. Note that other circuit board traces should be spaced away from the stripline to prevent signal coupling, as shown in Figure 4. The stripline trace should be kept short to minimize its insertion loss.

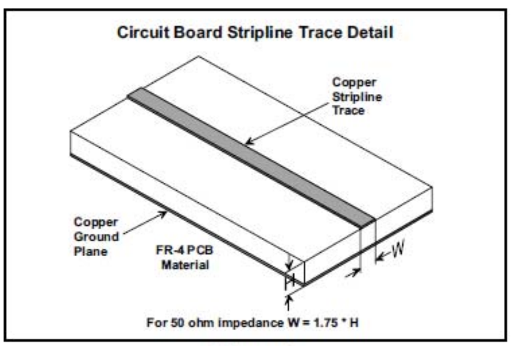


Figure 3

Trace Separation from 50 ohm Microstrip	Length of Trace Run Parallel to Microstrip
100 mil	125 mil
150 mil	200 mil
200 mil	290 mil
250 mil	450 mil
300 mil	650 mil

Figure 4

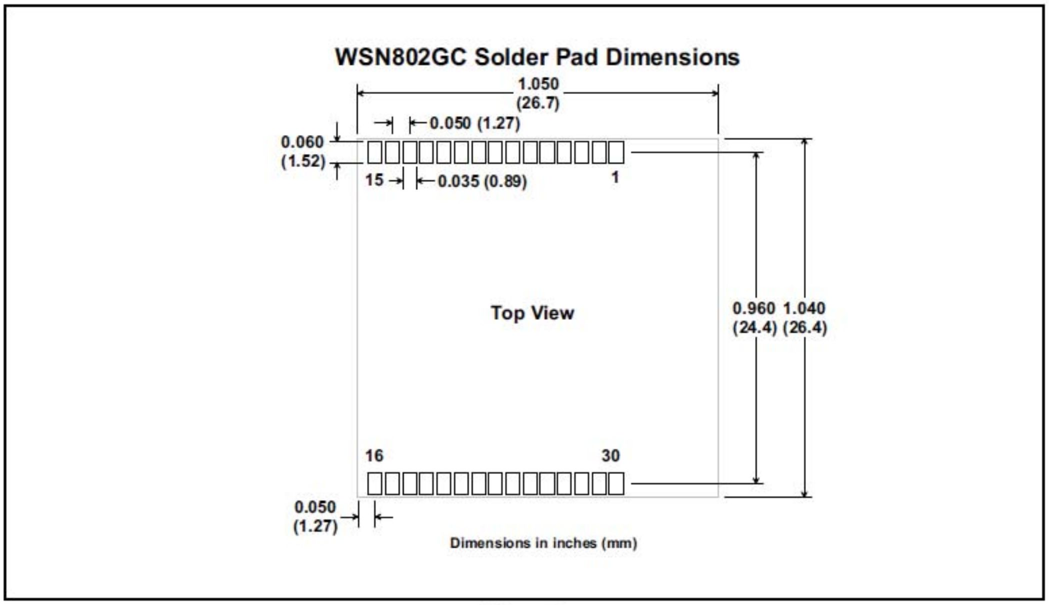


Figure 5

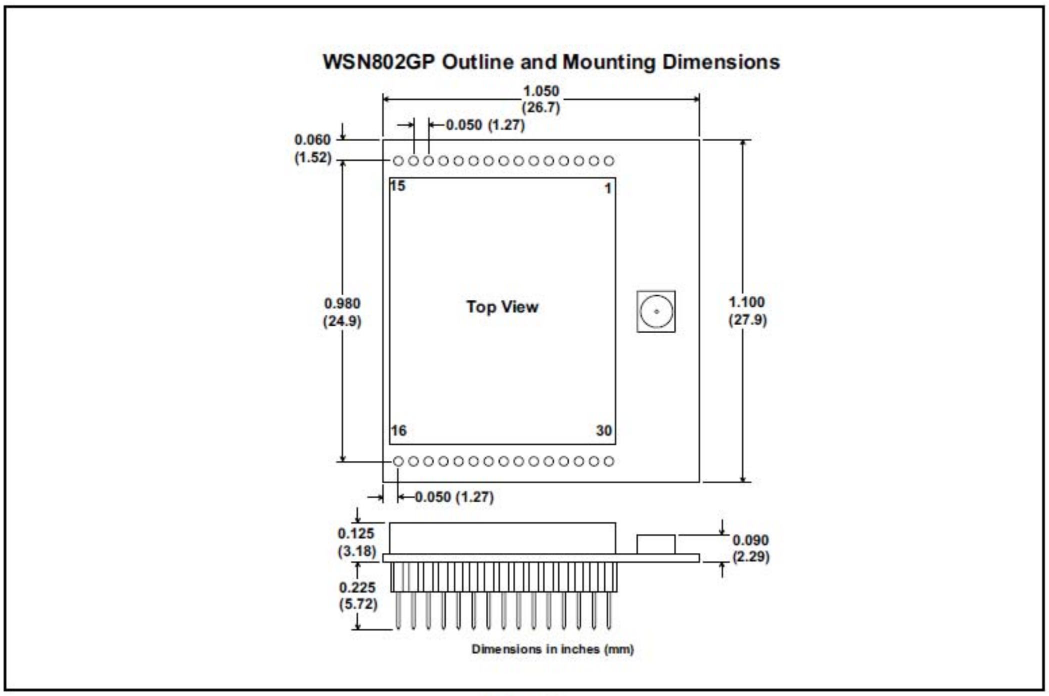


Figure 6

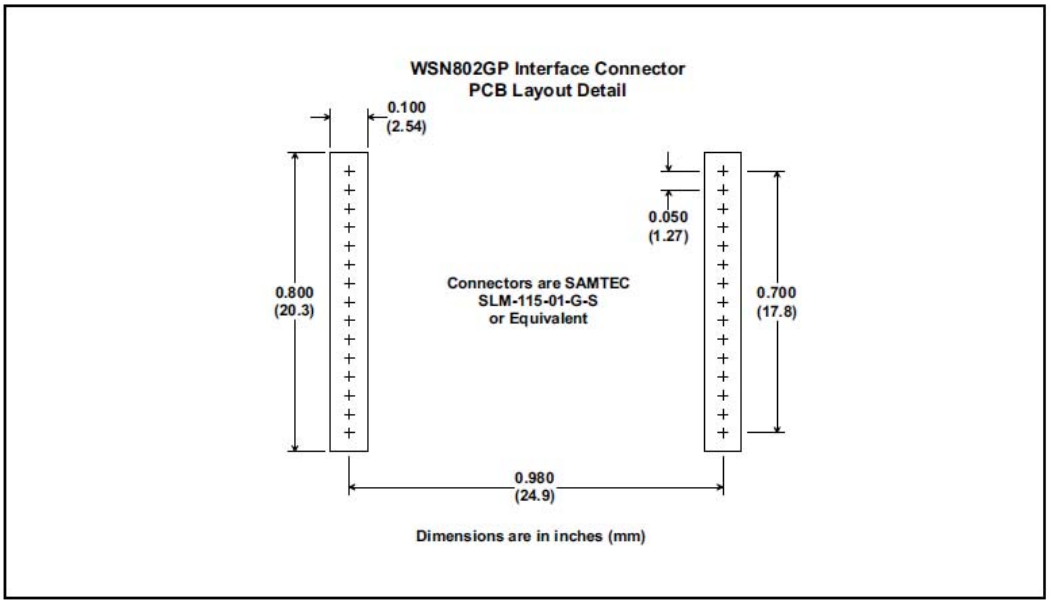


Figure 7

Note: Specifications subject to change without notice.

Part # M-0802-1000, Rev C